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ON

MODERN BITUMINOUS PRACTICE

HELD AT BUTTE, MONTANA

November 12th, 13th, and 14th

1935

MONTANA STATE HIGHWAY COMMISSION

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NAEGELE PRINTING CO., HELENA, MONT.

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(LETTER OF INVITATION TO MONTANA BITUMINOUS CONFERENCE)

Helena, Montana,
Sept. 10, 1935.

We want you to come to the Montana Bituminous Conference to be held in Helena, Montana, November 12, 13, 14.

Now a thorough bituminous conference should go into the subject from top to bottom—black top to Black Bottom. This conference will be plumb thorough. Authorities of national repute will appear on our conference program. You can't afford to miss them. There will be discussion periods when every delegate and guest will have an opportunity to cuss and discuss the subjects and offer new material.

We have arranged an inspection trip to cover types of bituminous surfacing constructed in Montana and provision has been made for an underground look at one of Butte's famous copper mines.

To keep you from bogging down in a morass of serious affairs we are interspersing the technical pyrotechnics with entertainment, varying from the frivolous to the fantastic. Tuesday evening, November 12, there will be an exclusive dinner dance and floor show at the Nite Owl. Wednesday evening there will be a haven for the parched at the Placer Hotel and those informal huddles that produce such unique ideas. Thursday evening there will be a stag dinner at the well-known Rocky Mountain Cafe at Meaderville, just out of Butte. A program has also been arranged for the ladies during the conference sessions.

If you will please check the enclosed form and return as soon as possible, we will sure appreciate the courtesy.

We are expecting you.

Sincerely,

MONTANA STATE HIGHWAY COMMISSION,

By D. A. McKinnon,
State Highway Engr.

SPECIAL PROVISIONS

Pertaining to

MONTANA CONFERENCE ON MODERN BITUMINOUS PRACTICE

November 12th, 13th, 14th, 1935
Helena, Montana

We know that if all of the words used up in just six average conferences were laid end to end, they would make a political campaign look like a deaf mute's monologue. So we don't expect nor want you to spend all of your time out here conferring.

We will give you a chance to go places and commune with Nature. In locating our highways, we haven't been materialistic to the point of going plumb commercial. We have taken into consideration this Nature thing.

We will show you spots where you can sit in your car putting together a split bamboo rod and the trout will come out of the stream and take your fly book away from you.

We will show you mountains that would give an Alpine climber vertigo.

We will show you a great variety of wild life, au naturel or bedizened.

We will show you—aw, hell, just walk in without knocking, throw your hat on the floor, and you'll feel right at home.

P. S.—Don't worry about the weather either. We have never had a banana crop frosted in Montana yet.

(LETTER ADVISING THAT MONTANA BITUMINOUS CONFERENCE WOULD BE HELD AT THE FINLEN HOTEL IN BUTTE, RATHER THAN IN HELENA DUE TO SEISMIC DISTURBANCES.)

MONTANA STATE HIGHWAY COMMISSION

HELENA, MONTANA

November 4th, 1936.

Dear Sir:

According to distorted and exaggerated reports, Helena has been shaking like a wet dog. We don't deny that the pine trees and sagebrush have swished around once or twice like the grass skirt on a tall Hula girl, but that hasn't made Quakers out of Us by a long shot.

However, for the benefit of those who are not accustomed to being rocked asleep by earthquakes, we have decided to hold the Montana Conference on Modern Bituminous Practice in Butte, November 12, 13 and 14 at the Finlen Hotel.

By way of extra entertainment, we will arrange a trip to Helena so that you can look the old town over and try a few of our mild temblors. Please bear in mind that no shivering scenery is going to bog this party down.

Very truly yours,

D. A. McKINNON,
State Highway Engineer.

THOSE PRESENT AT MONTANA CONFERENCE ON MODERN BITUMINOUS PRACTICE
Finlen Hotel, Butte, Montana, Nov. 12, 13, 14, 1935

LIST OF REGISTRANTS AT THE MONTANA CONFERENCE
ON MODERN BITUMINOUS PRACTICE

Butte, Montana, November 12th, 13th, and 14th, 1935

Archibald, M. H.	Nolan Bros.	Minneapolis, Minn.
Aldrich, J. D.	William Bros. Boiler & Mfg. Co.	Minneapolis, Minn.
Battin, W. R.	Standard Oil Company	Billings, Mont.
Batzer, H. O.	Home Oil & Refining Co.	Great Falls, Mont.
Bawden, W. E.	Resident Engineer	Montana Highway Com.
Benedict, A. H.	Materials Engineer	Bureau of Public Roads
Bourne, Don	Asphalt Institute	Washington
Bonesteele, S. C.	Resident Engineer	Montana Highway Com.
Boudecker, Lou	Chief, Highway Patrol	Montana Highway Patrol
Brown, Fred M.	Resident Engineer	Montana Highway Com.
Bruce, Chas. E.	Hall-Perry Mchy. Co.	Butte, Montana
Carpenter, H. B.	Standard Oil of Indiana	Denver, Colorado
Cheney, D. L.	Ass't. Bituminous Engr.	Montana Highway Com.
Clark, A. C.	Senior Highway Engr.	Bureau of Public Roads
Cobleigh, W. M.	Professor	Montana State College
Conkling, L. D.	Professor	Montana State College
Corbett, F. R.	Yale Oil Corporation	Billings, Mont.
Cox, C. E.	Yale Oil Corporation	Billings, Mont.
Compton, M. T.	Contractor	McMinnville, Oregon
Compton, J. C.	Contractor	McMinnville, Oregon
Compton, G. L.	Contractor	McMinnville, Oregon
Croonenberghs, L. J.	Member	Montana Highway Com.
Culp, W. A.	J. L. McLaughlin Const. Co.	Great Falls, Mont.
Cutting, O. E.	Senior Ass't., Office Engr.	Montana Highway Com.
Donohue, E. B.	Ass't. State Highway Engineer	Montana Highway Com.
Donlan, H. H.	Chemist	Montana Highway Com.
Dougherty, H. H.	Westmont Tractor & Equip.	Missoula, Mont.
DeMers, E. L.	Home Oil & Refining Co.	Butte, Montana
Dodson, L. E.	Field Engineer at Butte	Bureau of Public Roads
Eby, Earl	Elk River Concrete Prod. Co.	Helena, Mont.
Ehlen, C. M.	Utah Oil Refining Co.	Boise, Idaho
Engel, A. W.	Equipment Superintendent	Montana Highway Com.
Ephland, R. J.	Division Engineer	Montana Highway Com.
Ewing, R. L.	Resident Engineer	Montana Highway Com.
Eyer, C. E.	City Engineer	Glendive, Mont.
Ferguson, W. G.	Montanans, Inc.	Helena, Mont.
Flanigan, W. J.	Commr. of Highways	North Dakota
Fletcher, R. H.	Plans Engineer	Montana Highway Com.
Frosher, E. E.	Quaker State Oil Co.	Butte, Montana
Garrity, L. V.	Laboratory Supervisor	Michigan Highway Dept.
Gail, W. W.	Yale Oil Corporation	Billings, Mont.
Gillis, R. H.	District Engineer	Utah Road Commission
Gilmore, F. S.	Asphalt Institute	Kansas City, Missouri
Gnose, Ira G.	Project Engineer	Montana Highway Com.
Goodnight, C. A.	Chemist, Wyoming	White Eagle Oil Corp.
Gough, D. G.	Clerk, Plans Dept.	Montana Highway Com.
Gould, V. G.	Ass't. Bituminous Engr.	Iowa Highway Dept.
Gregory, H. W.	Hardesty Mfg. Co.	Missoula, Mont.
Groves, H. G.	Testing Engineer	No. Dakota Highway Dept.
Gray, W. J.	Yale Oil Corporation	Butte, Montana

LIST OF REGISTRANTS AT THE MONTANA CONFERENCE (Continued)

Hart, Scott P.	Maintenance Engineer	Montana Highway Com.
Hamilton, Joe	District Engineer	Washington Highway Dept.
Hatch, N. J.	Maintenance Clerk	Montana Highway Com.
Hay, J. H.	Standard Oil of Indiana	Billings, Mont.
Hafer, Max C.	Eton Metal Products Co.	Billings, Mont.
Healy, Jack	Silver Bow County Surveyor	Butte, Montana
Herrick, R. P.	Supt. McGuire Const. Co.	Butte, Montana
Higgins, J. F.	Accountant	Montana Highway Com.
Hicks, N. W.	Division Engineer	Butte, Montana
Hughes, C. P.	White Eagle Oil Corp.	Missouri
Hunt, Basil	Contractor	Butte, Montana
Jacobs, J. F.	District Engineer	So. Dakota Highway Dept.
Johnson, Guy	Division Engineer	Montana Highway Com.
Johnson, P. M.	Division Bridge Engr., Butte	Montana Highway Com.
Kay, R. C.	District Engineer	Wyoming Highway Dept.
Kelly, J. D.	Foley-Kelly Oil Co.	Butte, Montana
Kelly, R. E.	Yale Oil Corporation	Butte, Montana
Knowles, A. D.	Project Engineer	Montana Highway Com.
Kuhns, Ray	Resident Engineer	Montana Highway Com.
Kuphal, H. H.	Resident Engineer	Montana Highway Com.
Krchma, L. C.	White Eagle Oil Corp.	Missouri
Lahn, M. L.	Oil Inspector	Montana Highway Com.
Lang, F. C.	Engineer of Tests	Minnesota Highway Com.
Larson, Dick	Oil Inspector	Montana Highway Com.
Lawler, L. T.	Contractor	Butte, Montana
Leary, W. J.	Resident Engineer	Montana Highway Com.
Lockey, M. C.	Division Engineer	Montana Highway Com.
Lovejoy, W. N.	Bituminous Engineer	So. Dakota Highway Dept.
Loomis, Ray	Chemist	Montana Highway Com.
Loy, I. K.	Standard Oil of Indiana	Casper, Wyoming
Maguire, J. C.	Contractor	Butte, Montana
Mason, Seward	Testing Engineer	Montana Highway Com.
McDowell, David	Project Engineer	Montana Highway Com.
McCoy, N. F.	Highway Engineer	Bureau of Public Roads
McGhee, John	Resident Engineer	Montana Highway Com.
McKee, M. L.	White Eagle Oil Corp.	Montana
McKinnon, D. A.	State Highway Engineer	Montana Highway Com.
McLaughlin, J. L.	Contractor	Great Falls, Mont.
McLeod, N. W.	Research Engr., Dept. Hiwys.	Regina, Saskatchewan
McKenzie, H. R.	Chief Engr., Dept. Highways	Regina, Saskatchewan
McMillan, L.	Oil Inspector	Montana Highway Com.
Muir, Levi	Materials Engineer	Utah Road Commission
Myers, Ace	Union Oil Company	Washington
Myhre, Carl	Home Oil & Refining Co.	Great Falls, Mont.
Middleton, A. G.	Resident Engineer	Montana Highway Com.
Neill, J. E.	Resident Engineer	Montana Highway Com.
Newland, R. P.	District Engineer	Washington Highway Com.
Nevitt, H. G.	White Eagle Oil Corp.	Kansas City, Missouri
O'Brien, J. T.	Division Clerk, Butte	Montana Highway Com.
Olson, Sid	Midland Implement Co.	Billings, Mont.
Perry, John	Hall-Perry Mchy. Co.	Butte, Montana
Perry, Tom	Bituminous Engineer	Iowa Highway Com.
Percy, Ray	Resident Engineer	Montana Highway Com.

LIST OF REGISTRANTS AT THE MONTANA CONFERENCE (Continued)

Phillips, J. R.	District Engineer	Wyoming Highway Com.
Poore, George	Pre-Construction Engineer	Montana Highway Com.
Rader, Ralph	Bridge Engineer	Montana Highway Com.
Ramey, C. F.	Standard Oil of Calif.	Richmond, Calif.
Ratchye, Fred	Project Engineer	Montana Highway Com.
Reagel, F. V.	Engineer of Materials	Missouri Highway Com.
Ring, J. A.	Austin-Western Mchy. Co.	Bozeman, Montana
Roherty, J. N.	Research Engineer	No. Dakota Highway Dept.
Sagunsky, W. G.	Oil Inspector	Montana Highway Com.
Sanders, S. B.	Resident Engineer	Montana Highway Com.
Sampson, L. R.	Resident Engineer	Montana Highway Com.
Sawby, Irving	Project Engineer	Montana Highway Com.
Serumgard, A. F.	Computer	Montana Highway Com.
Shanley, W. B.	Universal Oil Prod. Co.	Chicago, Illinois
Steere, M. J.	Resident Engineer	Montana Highway Com.
Stoddard, E. A.	Ass't. Materials Engr.	Iowa Highway Dept.
Smith, W. K.	Anaconda Copper Mining Co.	Butte, Montana
Staples, C. F.	Anaconda Copper Mining Co.	Butte, Montana
Steffeck, A. J.	FWD Truck Company	Helena, Mont.
Stephenson, D. G.	Bridge Const. Engineer	Montana Highway Com.
Templeton, R. J.	District Engineer	Wyoming Highway Com.
Thompson, Pat	Union Oil Company	Seattle, Washington
Thompson, Willard	Sec'y., Chamber Commerce	Butte, Montana
Tilzey, H. C.	Division Engineer	Montana Highway Com.
Tilzey, Harold	Project Engineer	Montana Highway Com.
Whipps, W. O.	Secretary	Montana Highway Com.
Williams, L. D.	Independent Refining Co.	Billings, Montana
Woodward, M. W.	Contractor	Rock Springs, Wyoming
Woodward, G. E.	Resident Engineer	Montana Highway Com.

MONTANA CONFERENCE ON MODERN BITUMINOUS PRACTICE

Butte, Montana, Nov. 12, 13 and 14, 1935

OPENING SESSION

FINLEN HOTEL, 9:30 A. M., NOV. 12, 1935

D. A. McKINNON, MONTANA STATE HIGHWAY ENGINEER
GENERAL CHAIRMAN, PRESIDING

D. A. McKinnon, General Chairman, called the conference to order and presented Frank H. Cooney, Governor of Montana.

ADDRESS OF WELCOME

By Governor Frank H. Cooney,

Governor of the State of Montana

The presence of so many of you here today representing many sections of the United States and Canada is indeed a pleasing compliment to us of Montana, and to our highway system.

We are very proud of this highway system and I sincerely believe that this pride is rightfully justified and that our Highway Commission and its engineers should be highly complimented upon their record of road construction and maintenance.

I am very happy to have the privilege of welcoming you to Montana and I cordially invite you to inspect our highway system. Ten years ago, Montana was just beginning to start to "take itself out of the mud" but this has been a long, hard struggle. Our means of financing highway construction was for many years very limited. As you all realize, we have many acres of land and miles of road, but very few residents. Therefore, our income from regular sources of taxation was very limited. In 1929 a tax of five cents per gallon was levied on all gasoline consumed on the highways, this revenue going to the State Highway Fund. The results of this measure have been very gratifying and, added to our regular Federal Aid

funds, have enabled us to construct, improve and maintain many miles of highway.

In addition to this we have endeavored to take every advantage of all moneys which have been allotted by the Federal Government to our state to provide employment, so that to date $66,000,000 have been expended on our highway system. $11,000,000 more will be spent in the next year, which will complete all the connecting links in our main highway system and will also give us several hundred miles of secondary or farm-to-market roads which are also of vital importance to our state, due to the fact that none of our county systems now have the financial means with which to construct much needed roads of this type in well populated rural communities.

This eleven million dollars is all Federal funds, and in order to handle a construction program of this size, continue our regular maintenance, and provide for increased future maintenance, we will spend this year in addition approximately $3,500,000 on maintenance, purchase of machinery, administration, engineering, and other costs incidental to this program. This $3,500,000 will be received from the state gas tax.

This highway construction program has provided employment for a very large percent of our unemployed. The peak of highway employment was in July, 1934, when 8,943 persons were employed. During the past thirty months or since I became Governor, the average monthly payroll on highway construction and maintenance has been 3,655 persons. In that period we have oil surfaced 2,040 miles or sixty percent of all the oiling that has been done since our fine highway system was started, and we have constructed 742 miles of new highways. During this time we have spent $25,220,000 on construction and maintenance and of this amount $10,000,000 was paid in wages.

We have also recently organized a State Highway Patrol which is doing fine work and which we believe will produce far reaching results in promoting safer driving and eliminating accidents on the highways. The funds for the providing and maintaining of the Patrol were obtained from the sale of drivers' licenses, together with such penalties as might be imposed and this organization is now self-supporting.

In conclusion I wish to express to you a sincere hope that your conference here will be highly successful and that you will thoroughly enjoy your visit to Montana.

ADDRESS BY D. A. McKINNON

Montana State Highway Engineer

New and better highway standards, more uniform and highly controlled construction practices made necessary by the yearly increasing highway traffic throughout the United States, have, to quite an extent, changed and increased the work of highway engineers and highway commission.

The old understanding of the duties of the highway commission was merely that that body was to build highways with any moneys that became available. Now we have gone beyond that stage, and the Highway Commission of today must also seek additional revenue to maintain constructed highways, and to provide funds for the improvement of projects constructed under the old standards where it is necessary to reconstruct to eliminate dangerous curves, reduce mileage, and otherwise secure a better alignment, widen the roadbed, or raise the grade line to improve riding qualities, drainage, or snow conditions. They must also seek funds with which to expand and increase the existing highway system.

The Montana Highway Commission has taken active steps in this direction by seeking to bring the tourists into the state. We conducted a tourist traffic industry survey in Montana the past season, during the months of July, August and September. Final computations on yearly tourist traffic based on this survey were just recently completed and we have found that there were 1,296,000 visitors from other states, traveling in 410,000 automobiles, who came to Montana during the year. During their stay in the state they spent approximately $23,351,000.00.

This sum left in the state by tourists this year is nearly as much money as the total expended by the state for the construction and maintenance of roads in the last three years. Of this amount about $5,303,000.00 was spent for gasoline. From this the state realized approximately $1,325,764.00 in gasoline taxes, about one-third of the total income received in the state from all gasoline users. We regard the proceeds from the gas tax within the state as a fairly stable supply, now

near the saturation point, but it is this tourist volume which can be increased and which we intend to increase in order to expand our revenue. Expansion of tourist trade will enable construction of better roads, providing more tourists which, performing a complete circle, provides still greater revenue for still further improvements. We want to make American tourists and vacationists Montana-minded. Frankly, Montana has entered a competitive business in tourist attraction, and improved dustless highways are the main features of attraction.

Therefore, for this purpose not only must our own roads be highly attractive, but the roads of our neighboring states, who may also derive large financial benefits from this traffic, through which the tourists must pass, must be equally attractive.

It has then become necessary, with these steadily increasing demands for smooth, safe, dustless highways, to secure a surface of this type at the lowest possible cost. Bituminous construction will meet this demand, fulfilling all requirements, Not only are bituminous surfaces low in cost, smooth, dustless and safe, but this type of construction is to a great extent permanent and the material originally used can be to quite an extent at any time salvaged or reconstructed, without too great a loss, to meet increasing demands for width, alignment, and smoother riding surface.

Knowing that all other Western states were vitally interested in bituminous construction, the Montana Conference on Modern Bituminous Practice was originated by the Montana Highway Commission with the idea of bringing together the engineers of the various states to meet in a mutual effort to work out a program for higher and better type bituminous constructed highways and to bring about a practical discussion of problems, methods, and results by men who were really familiar with bituminous construction and who had demonstrated their ability to get results on their own highways.

We seek particularly to interest states in the development of roads of low construction cost, but with a high degree of satisfaction as regards dustless, smooth and safe requirements, and it is our hope to accomplish this purpose through the means of the Montana Bituminous Conference.

Papers Presented on

FUNDAMENTALS OF SUCCESSFUL BITUMINOUS PRACTICE

Presiding: J. W. Hamilton, District Engineer
Washington State Highway Department

SOILS AND SUBGRADE

By F. C. Lang, Professor of Highway Engineering, University of Minnesota, and Engineer of Tests, Inspections and Research, Minnesota Highway Department

At a conference on modern bituminous practice, soils and subgrade are presumably of most importance as a support for a bituminous wearing surface. This paper will therefore be largely confined to that phase of soils work.

The speaker is not very familiar with conditions in this area and therefore must, for the most part, base his remarks on Minnesota conditions. The engineers who are in charge of bituminous construction and maintenance in Minnesota are generally of the opinion that the western states have advanced further in bituminous road construction than either the mid-western or eastern states. Motorists are very enthusiastic about the western roads. Perhaps your conditions are more favorable for the bituminous type of road.

The objective then, for the Soils Engineer, is to get a uniformly and adequately firm support for the so-called flexible bituminous surface. This would include the design of the base when soil testing methods are used in the selection and proportioning of base materials. As yet, we have no standard procedure for obtaining suitable support for the flexible surface, and methods vary widely throughout the United States. A variation in procedure is to be expected where there are different soil conditions, different climatic conditions, different traffic conditions and different engineers basing their judgment largely on experience.

Formulas for Subgrade Support

It is a recognized fact that research and experience have not as yet placed any tool or method in the hands of road build-

ers for accurately determining the bearing power of subgrades for flexible surfaces. This is quite necessary before any very rational design of the wearing surface or base course can be made. During the past year there have been some publications of formulas for designing flexible bituminous surfaces. A statement by Mr. Kelley of the Bureau of Public Roads in a paper presented at the annual meeting of the Highway Research Board covered these formulas at that time and for that matter, in the speaker's opinion, still does. Mr. Kelley said, "Attempts have been made to develop a rational theory but these are based on questionable assumptions of such far reaching importance that they can scarcely be accepted without verification by further research." It is the opinion of some engineers, that entirely new theories have to be developed and confirmed. The soils do not support a static load, but instead, a load that passes over them very rapidly. This time element should be given consideration.

Soils Organization

While research has not as yet developed a satisfactory tool or method for evaluating subgrade support, considerable progress has been made in soil studies. Engineers now know that soils work is highly specialized and is going to be more so in the future. This means that soils work can be carried on successfully only by men who have made a special study of soils. The work requires a special investigative type of individual, and to be successful, he must have a thorough education. It is desirable to obtain an outstanding engineering graduate who has taken special graduate work on soils. Soils work is too technical for ordinary practical men, or for most political appointees. The benefits to be gained by the work of competent soils engineers are so great that no chances should be taken in trying to carry on this work with incompetent men.

The particular type of soils organization to adopt will vary according to local conditions in the various states, but non will be really successful unless the right type of men are selected. The pay should be such as to attract and hold good men.

In Minnesota, Soils Engineers with some laboratory equipment are placed in each of the eight District Engineer's territories. They are under the technical supervision of a State Soils Engineer whose headquarters are at the central office in St. Paul. The District Engineers tell them where to work, but not how to work. They are on the payroll of the Division of

Tests, Inspection and Research. They are not burdened with administrative, research or unnecessary detail work. They are assigned to a definite area so that they will become familiar with the geological and road conditions in a section of the state. Also, they have to live where their mistakes are made.

The duties and responsibilities of this organization may be summarized as follows:

1. To examine defective places in existing roads, ascertain causes, and design corrective measures.

2. To see if tentative grade line on proposed construction will encounter objectionable soils; and if it does, either recommend a change in grade line or alignment, or plan corrective measures.

3. To decide on the adequacy of the foundations or subgrade for the surface course.

(a) This may involve the design of stabilized bases and temporary stabilized wearing surfaces.

(b) In some cases, it may be necessary to design a drainage system.

4. To select soils for shoulders, binder soils for stabilized gravel, and soils for other special purposes.

Gravel Bases

A bituminous surface must have subgrade support. It is the soils engineer's job to provide this at least cost. In Minnesota this usually means proportioning the components in a gravel base and deciding on the thickness of the base along the road according to the supporting power of the underlying subgrade. The variation in thickness is based on the knowledge and experience of our soils engineers. The necessary thickness varies according to the elevation of the road above water table and the nature of traffic as well as soil conditions. To convey some idea the following thicknesses of bases are given for the different soil groups:

A-1	None
A-2	Generally 3″
A-3	Binder only
A-4 & 5	6″
A-6 & 7	3 to 12″

It is now the intention to stabilize all bases in 3″ layers. The upper 3 inches is to serve as a wearing surface until consolidation has taken place. This would probably about require a year under traffic. It is now the practice in Minnesota to use calcium chloride in the upper 3 inches. There have been a few disastrous experiences when thick layers of unstabilized gravel were placed on heavy soils. The following is an illustration:

A certain road in uniformly heavy soil (A-7) was graded in 1933. The grade line was about 4 feet above the bottom of wide ditches. On one end of the road about 6 inches of gravel was placed in two courses and stabilized while the subgrade was dry. The road has been in good condition ever since and is in excellent condition at the present time for a bituminous surface. On the other end of the road, the same amount of unstabilized gravel was placed in 1933, on a subgrade that had been oiled. During the spring and early summer of 1934 the moisture from the snow and spring rains went down through the gravel and soaked into the subgrade. It rutted, worked up into the gravel in ridges and the road became impassable. This was in the spring of 1934 and while considerable effort has been made since to dry out the subgrade and to construct a bituminous surface, the road is still spongy and unstable.

A porous gravel mat of any thickness acts as a reservoir and should not be laid on heavy soils in humid areas. Stabilized mats shed the water. They can be constructed to have 10 per cent or less voids.

Improving Supporting Power Natural Soils

In Minnesota the engineers have had no experience with the use of admixtures to increase the load carrying capacity of plastic soils by adding Portland cement, emulsified asphalt, or other materials. About ten years ago, oiling a heavy soil and then using a light application of gravel was tried. This practice has been discontinued except on a few very light traffic roads. The roads seemed to get worse with time.

Frost Boils

In Minnesota, the most disastrous time for the flexible bituminous surfaces is during what is locally termed, the spring break-up. If the foundation support is adequate during that period there is very little danger of failure during the remainder

of the year. For some years, we observed that in the spring, the road might be generally good, but was made practically impassable by the extreme softness of the subgrade on a few short stretches. Practical road men tried a number of their pet remedies, but because the reasons for the phenomena were not understood, they usually failed. Some noticed that in a number of places where the road was impassable during the spring break-up that there was a bump in the road during the preceding winter. The cause of these heaves and subsequent frost boils is now known.

The following explanation is taken from the June, 1931, issue of "Public Roads":

"Heaving of soils due to frost action is caused by an increase in total moisture content occurring as ice layers or crystals. Its magnitude depends upon the rate of temperature change, the moisture content of the soil prior to freezing, the proximity of additional water and the rate at which capillary flow occurs.

"The formation of well defined ice layers in the soil depends on three physical phenomena:

"(a) The tendency of water particles contained in soil pores of the larger capillary dimensions to freeze at either normal freezing temperatures (-1°, -4°C.)

"(b) The tendency of water particles contained in soil pores of the smaller capillary dimensions to resist freezing at abnormally low temperatures (as low as -70°C.)

"(c) The tendency of water particles of freezable size, during the process of freezing, to draw to themselves from adjacent fine capillaries the small particles of water which individually do not freeze at ordinary freezing temperatures. When drawn to the existing ice crystal these small water particles freeze and increase in size. Continuation of the process causes the original ice crystals to increase in size as long as they are being supplied with small water particles drawn up through the fine capillaries from the ground water supply.

"Whether or not frost heave will occur depends upon the quantity of moisture cabable of being raised to a given height above the water table in a given time. Neither the height to which water will rise by capillary nor the rate of such rise is alone the determining factor. Just as the amount of water

furnished by a pipe depends upon the pressure acting on the water, the diameter of the pipe and the frictional resistance to flow, the raising of a quantity of water sufficient to produce frost heave in the subgrade at a given height above the ground water elevation (disregarding the rate at which capillary equilibrium is destroyed) depends upon the force of capillarity, the area of pore space, and the frictional resistance.

"Capillary pressure varies inversely with the diameter of the pores. The frictional resistance to flow through a soil is a function of the surface area of the soil particles and consequently increases with a decrease in grain size at a much greater rate than does the capillary pressure. Therefore, in order to furnish capillary moisture in detrimental amounts the pore size must be small enough to furnish appreciable capillary pressure but large enough to prevent too much frictional resistance to flow.

"As an indication of the amounts of water furnished by capillarity, it has been estimated that certain Iowa silts are capable of raising water by capillarity at the rate of about 5 feet per year. It is indicated by observations in both New Hampshire and Minnesota that in extreme cases the rate may be as high as 10 or 15 feet per year.

"Generally it can be stated that in cohesionless soils possessing but little capillarity no important frost heaves occur because practically all of the contained water particles do not exist in amounts sufficient to cause the frozen particles to suffer appreciable growth. Soils possessing relatively high capillarity and relatively low cohesion are likely to heave in very appreciable amounts.

"Highly cohesive soils may possess very high capillarity but the resistance to water flow in these soils is very great. Consequently in dense cohesive soils with low ground water level and absence of lateral seepage, only limited amounts of water are available for ice segregation. Under these conditions the soil adjacent to the growing ice crystals, is likely to dry out and shrink because of the loss of moisture. The ground water elevation in clays, therefore, must be comparatively high in order that important frost heaves may occur."

The bumps or short heaves on the roads occur because the conditions there are more favorable for the growth of ice lenses than in the rest of the road. The heaves usually occur

where silt soil comes near the road surface, and water is supplied to the silt by adjacent stratum or pockets of sand. In glaciated areas there are likely to be considerable variations in the soil texture encountered in cuts.. The differential heaving usually occurs in cuts, although where soil types vary and the grade line is low, they have been known to form on fills. The ice lenses occasionally form to such an extent that the road surface is raised a foot, but usually the heaves or bumps are much less.

The frost boils are the after-effect of the heaving. In the spring when the ice melts it liberates a large amount of water which has no outlet. It cannot soak into the soil below because the frost is not out of the ground. As a result, the soil is saturated with only a thin, dry crust at the road surface. A heavy vehicle may break through this surface crust, particularly when it has been softened by rains. Once the surface crust is broken the vehicle can get no farther under its own power and must be pulled out. The hole is enlarged by subsequent vehicles, and the final result is a few feet of quagmire.

The next question is how to correct this condition. One's first thought is naturally to drain the liberated water away. This would not improve the surface for winter driving, but might improve the road during the spring break-up. Drainage is possible; for while the capillary water cannot be removed by tiling placed above the natural water table, the water liberated by the thawing ice can be. In cases, however, where tiling has been placed for this purpose, and the trench was backfilled with coarse granular material so that the water would have easy access into the tile, there were serious consequences. The ground over the tile did not heave because the capillary water did not rise in the granular backfill. Inasmuch as the road surface on either side of the trenches did heave, it made the road in this location very uncomfortable and even hazardous for winter driving. The placing of tile near the surface is therefore not feasible on account of its effect on the road surface during the winter.

The best solution, therefore, seems to be to remove the offending soil when the heave and rsulting frost boil occur in cuts and backfilling with granular material. This should be done only after an examination by Soils Engineers, and according to plans prepared by them. The depth of the excavation

and the granular backfill apparently does not have to be the full frost penetration. In Minnesota, a depth of 30 inches in the northern part of the state, and somewhat less in the southern, appears to be sufficient. When the heave occurs on fills, it is usually advisable to raise the grade line. When there are bad soil conditions on fills, it is advisable to place a substantial layer of gravel at least six inches and preferably twelve inches.

Conclusion

The time allotted for this paper has not permitted a description of the real progress made in soil research during the past decade. Many basic facts have been established. The research workers in this field must be stimulated by the possibilities of the far reaching effects of new discoveries. What a benefit it would be to mankind, if one could, at low cost, use or manipulate the materials naturally available so as to make a good all year road.

FOUNDATIONS ABOVE THE SUBGRADE

By N. F. McCoy, Highway Engineer,
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The term "subgrade" is variously defined in highway specifications, a common definition being "The surface upon which the pavement or wearing course is to be placed." However, unless the point at which subgrade treatments end and foundations above the subgrade begin is defined, the vertical limits of my subject are quite indefinite. As Montana specifications do not define subgrade at all, I infer from Mr. Donohue's letter that I may go as deep as I choose, provided I extricate myself in fifteen minutes.

For the purpose of this discussion, Idaho's definition of subgrade surface as "The bottom of the excavation and the top of the fill," appears to be the best. The material below that surface has been discussed by Prof. Lang. I will discuss the subjects of depth, width and qualities of material that should be placed on the subgrade surface as above defined, to support a bituminous wearing surface.

That the bottom of the excavation and the top of the fill should not also define the limits of the activities of the grading and surfacing design divisions, is now generally recognized. Many a designer has been called upon to design bituminous surfacing for a graded adobe road, say 26 feet wide, with instruc-

tions to provide a 20-foot surfacing with 3 -foot shoulders. He must either convince himself and,unfortunately, others, that the subgrade is not really bad, or that a 22-foot or 24-foot roadway width is enough; or, he must provide for removing eight inches or a foot of the adobe subgrade and backfilling with good material. Fortunately, such situations are being presented less often. Most grading designers now understand that sufficient widths must be provided for subgrade reinforcement, and that for unfavorable soil the total depth of subbase, base and top surfacing for bituminous work should substantially exceed the traditional six inches.

The general nature of the problem of designing flexible surfacings needs little discussion. The function of the surfacing is to provide a wearing surface and to reduce the probable unit pressure on the subgrade to an amount that is less than its unit bearing power, under the worst seasonal conditions. With pit run or crushed stone, or even true macadam bases, the area of subgrade carrying most of the load is small, when compared with the effective supporting area under a rigid pavement. Tests by the Bureau indicate that a load placed on a concrete slab four inches thick exerts a maximum unit pressure on a clay subgrade equal to that exerted by the same load when placed on a crushed stone layer 42″ thick. This is not a plea for rigid pavement; I am simply emphasizing the points that with flexible surfacings the unit pressure transmitted to the subgrade are high, and that the loads are transmitted to relatively small areas of the subgrade. Uniform bearing values as well as sufficient bearing values, are essential.

The mathematical relation between depths of flexible base and pressures transmitted to the subgrade has been given considerable study. Formulae thus obtained, when related to the supporting value of the subgrade soils, will be of interest.

For the theoretical supporting value of soils when loaded over a long, narrow strip, Dr. Charles Terzaghi suggests the following:

	Supporting value lbs. per sq. in.
Clay, very soft	6
Clay, soft	13
Clay, fairly stiff	34
Clay, very stiff	87
Sand gravel mixtures, cemented	124

The above tabulation covers two classes of material: Clay, with varying moisture contents, and cemented sand and gravel. The bearing power of clay varies from only 6 lbs. per square inch for very soft clay, to 87 lbs. for very stiff clay. Adobe subgrades show an even greater variation in bearing power with changing moisture content than does the clay reported above. On account of the large areas in which they occur, they present a tremendous subgrade problem to western highway engineers. The good gravels, "d.g's" and sandy loams I am therefore eliminating from this short discussion; they present few serious foundation problems.

Except possibly in the genuine desert regions, there are few places in the West where moisture may not produce critical conditions for oiled roads on adobe subgrades. Even with good drainage, adobe subgrades will absorb water, as, unlike some of the clays in the Middle West, adobe does not lose its capillary power by being compacted. It will lose this water slowly, even if uncovered. If sealed against evaporation, an adobe subgrade can never dry. In fact, the moisture content of an adobe subgrade under a bituminous surfacing probably increases from year to year even in relatively dry areas. This probability is indicated by some test data and by the number of oiled roads that give good service for three or four years and then fail, through subgrade failures with moisture indicated as the cause of the subgrade weakness, and no unusual weather conditions to account for the high moisture content.

Tests of adobe subgrades under concrete pavement made during the dry season in California indicated moisture contents of 10% in the shoulders and slopes a few inches under the surface, and 25% to 35% a few inches below the center of the pavement. With such high moisture content, adobe has a low supporting value. Thus, to reflect the worst seasonal condition, adobe subgrades should not receive a higher classification than "soft clay," for which Prof. Terzaghi assigns a supporting value of 13. Making a very modest provision for a factor of safety, we could assign a bearing value of say, 10. Consulting Engineer Sheets of the Cement Association suggests a value as low as 5# for soft plastic clay soil, so my modest factor of safety may in fact be non-existent.

Most of the formulae stating a mathematical relationship between required depth of flexible surfacing, wheel load and

soil bearing value, are based on the assumption that the wheel load is supported by an area on the subgrade bounded by the line obtained by projecting downward at a 45 degree angle from the point, or line, or perimeter of area of application of the load. This is the "cone of pressure" theory. Static loads only are ordinarily considered, though some of the authorities recommend that actual loads be increased 50% for impact. The further assumption that the load is uniform within this area must also be made. The derivation of these formulas is then a matter of simple geometry.

Harger and Bonney considered that the load was applied through a line whose length equals the width of the tire "T," and suggested the formula

$$D = \sqrt{\frac{W}{3P} + \frac{T^2}{9}} - \frac{T}{3}$$

Where D = Depth of surfacing, inches
W = Wheel load, lbs., inc. impact
T = Width of tire, inches
P = Safe bearing value of soil, lbs. per square inch.

Mr. Sheets states that this formula agreed with actual experience in the Bates Road Test. Twelve variable thickness flexible sections were built on a clay subgrade with a supporting value, determined by loading tests of 10 pounds per square inch. Varying wheel loads were applied to the pavement and when the subgrade pressure, calculated by Harger and Bonney's formula, exceeded 10-pounds, failure quite consistently occurred.

Prof. Downs considered that the load would be applied at a point and advanced the formula:

$$D = 0.564 \sqrt{\frac{W}{P}}$$

Mr. Bernard Gray, Chief Engineer of the Asphalt Institute, believes that if pneumatic tires were used, the load would be applied through a circular area of radius "e." This area would depend upon the size of the tire, which ordinarily is governed by the load. Mr. Gray advances this formula:

$$D = .564 \sqrt{\frac{W}{P}} - e$$

"e" will vary from 2.8" for a 2,000-lb. wheel load, 4.9" for a 6,000-lb. wheel load, to 6" for a 10,000-lb. wheel load.

A number of more elaborate formulae based on different and possibly more accurate assumptions have been advanced, but consideration of the above will suffice for the present

purpose. Let us compare the values obtained by assuming a certain set of conditions and substituting the corresponding values in the three formulae.

Assume an 8,000 lb. wheel load composed of a 6,000 lb. direct load and 2,000 lb. impact, a 10-inch tire, a value of 4.9″ for "e," and an adobe subgrade with a bearing value of 10 lbs. per square inch.

Substituting in the formulas, we find that:

Harger and Bonney gives	D=13.3 inches
Downs' Formula gives	D=15.9 inches
Gray's Formula gives	D=11.0 inches.

If we assume a fair soil to which we can assign a supporting value of 20 lbs. per square inch:

Harger and Bonney gives	D= 8.6 inches
Downs' Formula gives	D=11.3 inches
Gray's Formula gives	D= 6.4 inches

For a soil whose bearing value is 5 lbs. per square inch, the depths of surface required for the same load would be as follows:

By Harger and Bonney formula	20.0 inches
By Downs' Formula	22.5 inches
By Gray's Formula	17.6 inches.

The least depth indicated for the 10# subgrade by any of the three formulae is 11 inches. This is more than the total depths used by many western designing engineers for bituminous construction on ordinary adobe subgrades. For the same load, the least depths indicated for subgrades having 5#, 10# and 20# supporting values are, respectively, 17.6″, 11″ and 6.4″.

These figures are indicative of the required total depth of sub-base or ballast, base course, and top course. For the greater depths, sub-base courses of cheaper material than the usual crushed base course surfacing naturally suggest themselves. The Bureau of Public Roads and a number of the states now make extensive use of such material, under the names of subgrade reinforcement, sub-base material, ballast, special borrow, etc. The material ordinarily used is pit-run gravel, or rock fragments from talus slides. Such material with sufficient sand and silt to form a reasonably dense mat, when it has become thoroughly compacted, serves the purpose very well.

However, due to the latitude in grading and construction procedure usually permitted by the specifications to obtain low prices, some increase in total depth over the figures indicated by the formulae is in order, to compensate for a probable lack of uniformity. When we consider that sub-base material frequently costs only 35c to 50c per cubic yard, and that with proper grading design, it will frequently replace ordinary borrow costing, say, 20c, adequate sub-base courses are not ordinarily costly.

The above formulae are not accepted as Gospel by everyone. Objections have been made to allowing as much as 50% impact for smooth, oiled surfaces, and to considering impact at all when the stress analysis is based only on a static load. Objections have also been made on the ground that an entirely different and much wider distribution of stresses will be set up under a moving load. Some apparently believe we can pass over any subgrade, with the heaviest load, if we only go fast enough.

California has worked out a tentative curve, not yet published, showing the relationship between combined thickness of base, sub-base and wearing surface, and a soil quality designated as "The % Bearing Value." This quality is evaluated by an empirical test on a subgrade sample that is compacted in a 6″ cylinder and then soaked in water for four days. The load is applied through a disk having an area of three square inches. The loadings producing penetrations of .1 inch, .2, .3, .4 and .5 inch are recorded and stated as a percentage of "standard loadings," which are based on similar tests on good crushed stone. For a subgrade soil having a 20% bearing value, the curve indicates a 6″ total depth; for a 10%, about 9″; for 5%, about 15″; and for 3%, 18″. Under their test, adobe receives a 1% to 3% bearing value, indicating that 18″ or more, total depths of surface is required.

We can summarize the controversial subject of depth by saying that on adobe subgrades, even in relatively arid regions, we should provide a minimum total depth sub-base, base and wearing surface of about 12 inches. There is also good support for the statement that the adoption of an 18″ minimum would not mean wanton extravagance. It is, however, necessary only that the upper layers be of standard crushed stone or crushed gravel. We can exercise our talents for economy in a search

for cheap local material for the lower courses, and in making full use of suitable sub-base materials occurring in excavation. In the long run, there is no economy to be realized from inadequate total depths. We can build up the proper total depths by stage construction, but should be sure that the correct depth is provided for when we finally arrange to spend $5,000 to $10,000 per mile for a permanent bituminous surface course.

The next important dimension to consider is the width of the foundation above the subgrade. Surfacing the full width of the roadway with sub-base and base is now standard practice. The old "trenched" section was developed for untreated crushed gravel or crushed rock surfacings, its one justification being first cost economy. It had its faults, even when untreated material was used. In heavy soils, the trench no doubt impounded water. However, with warm weather evaporation functioned to decrease the moisture content, and in many areas by the time heavy traffic on the highways resumed, the subgrade had regained most of its supporting value. The picture is entirely different now. Bituminous tops seal the moisture in, and with snow removal oiled roads are subjected to traffic under the worst seasonal subgrade conditions. The desirability of placing sub-base and surfacing full width on new work is generally admitted, but there is still frequent reluctance to remove existing adobe shoulders when a bituminous top course is proposed on an existing trenched base course. Admitting that the job is rather a fussy one, the total cost of removing the earth shoulders and replacing with suitable stone is ordinarily not great. It should be done, even when a fairly heavy additional course of base material is contemplated, as this trench, if permitted to remain, will always be a source of weakness.

One state has recently adopted the scheme of using a steeper crown on the subgrade than on the roadway surface, placing the base or sub-base with the thickness at the shoulders correspondingly greater than that at the center. This appears to be an excellent procedure, and is suggested to all of you for consideration.

Very few statements, other than quite general ones, can be made regarding the quality of materials to be used in base and sub-base courses. Local availability usually governs. As a basis of classification of sub-base and base, District 2 of the Bureau, in Forest and Park road design, ordinarily proceeds on

the basis that the total thickness of base and top is to be six inches. Material below that place is classed as subgrade reinforcement, which on unfavorable soil, is placed in sufficient quantity to produce a bearing value high enough so that the standard six-inch surface course will support the traffic.

Hard, durable crushed stone or gravel should be used in the top six inches—base and top—as unit pressures are relatively high near the load. For the same reason, the base must be well filled and compacted, and must not include earth or clay filler of a type that is susceptible to moisture. Some of the states have made extensive use of true waterbound macadam bases, especially with wearing surfaces of the bituminous macadam or heavy surface treatment types. This type is no doubt the most stable, though unless good stone is locally available, and the contractors know how to crush it cheaply, it is quite costly. With crusher run bases, it seems unnecessary to hold down the size of fine crushed base material to one inch. If the proper construction procedure of thoroughly compacting the base before top construction is attempted is followed, there should be little difficulty with oversize in the top, even if it is road-mixed.

Sub-base material receives lower unit bearing stresses and need not possess the qualities of hardness and durability essential to the base course. However, as with the base, the material and any filler mixed in it, should be of a type that retains its bearing value during the spring break-up. Otherwise, the subgrade reinforcement doesn't reinforce at the time it is needed. If material suitable for this purpose is not available at reasonable cost, we must investigate the possibilities of subgrade treatments such as stabilization with asphaltic emulsion, admixtures of sand or other methods the efficacy of which, for the particular type of soil involved, has been proven.

To conclude: While the dimensions I have suggested involve more initial construction cost than the lighter designs frequently provided, designs with ample factors of safety will be more economical in the long run. I say this with full knowledge of the fact that many roads of much lighter design than here advocated have rendered good service for several years. However, a bad seasonal combination of heavy Fall precipitation and a cold winter or a backward spring always seems, sooner or later, to result in the failure of these thin roads. Obviously, we should design for the worst weather combinations

possible, just as a bridge is designed for the worst possible combination of loading conditions or flood conditions. The large number of bituminous road failures ascribed to unusually severe winters, unusually wet falls or unusually late springs, leads me to remark that California, contrary to popular opinion in the West, does not have a monopoly of unusual weather.

SELECTION OF PROPER TYPE OF BITUMINOUS SURFACING

By N. G. Nevitt, Manager Road Oil and Asphalt Division, Socony-Vacuum Oil Company, White Eagle Division

After the highway engineer has logically determined that for a given section of road a bituminous surfacing offers the best combination of service and economy, and has reached the point where he must determine the proper type to use, he finds the number of accepted well designed types so large that a crtain feeling of confusion is felt. This is true even of those experienced in bituminous construction. As a result, the selection of types in many cases has been quite arbitrary and the need for some logical method of determination is obvious. Many factors, considerably and not always simply interrelated, enter into the choice. Rules consequently present inherent difficulties. The subject, however, is capable of some logical systematization.

The method of attack will be the presentation of the basic or fundamental principles underlying bituminous design and construction, from which will be derived general rules and secondary principles of more immediate use. Logical selection depends upon understanding these basic principles which are often agreed to in theory but neglected in fact.

This method will not give an exact formula, but will indicate that a more rational selection is possible than is now made. Its application should result in a much desired wider use of available types. Evidently the considerable number of types which have shown ability to survive must have done so because of basic merit for some condition. Whenever an engineer traveling from state to state notes an apparent restriction to one or two arbitrary types, he cannot help but feel that their selection has not always been on entirely rational grounds.

The first, but often neglected, fundamental step in design or selection is to clearly outline the functional objective of the

surfacing under discussion. Just as conditions vary greatly, so do intended purposes. For example, let us take two roads the importance of which necessitates immediate surfacing. The first is a road on which the foundation conditions are uncertain, possibly as a result of rather recent construction. Quite evidently this should receive a light type or thin mat treatment. The other road nearby has a heavy, thoroughly established base on which only a light treatment to give a dust-proof surface is needed. Both roads specifically require a light mat, which too often would mean in many states the same treatment according to the same specifications whereas the ends to be obtained are entirely different. The former should be given a light but flexible load distributing treatment of low first cost rather than ultimate expense. The precaution should be taken of setting up the job so that further stage treatment or extensive maintenance can be provided in case this is indicated by developments. The latter road which requires primarily a hard non-skid surface with a long life, susceptible to economical maintenance, should receive a preliminary armer coating. A clear outline of the functional objective results in surfaces being built according to logical construction rather than according to certain set and standardized specifications for all such treatments.

The next fundamental is that the proper bituminous surface is the one which attains the objective at the lowest ultimate cost. Economic engineering methods, well known and proven in use, can and should be followed to determine these costs, either referring the entire cost of construction and maintenance to an annual charge basis or amortizing it to an initial total first cost. Here again it must be remembered that all the factors in the intended purpose of this surfacing must be brought into the cost picture. An essentially temporary surfacing, either due for relocation or to prove the suitability of the base previous to further stage treatments, should be looked at from a different cost angle than a permanent treatment. Or in the case of states dependent almost entirely on Federal Aid, and lacking in state maintenance funds, there should be a proper weighting between the investment cost and the maintenance cost, without blind adherence to either the lowest maintenance cost regardless of original investment or of too much economy in first cost at the expense of uneconomical maintenance. This principle of ultimate economy must be followed through consistently. A program of

stage construction designed to give immediate utility to a large mileage cannot shortly afterwards be treated in maintenance budgets the same as another type of heavier construction.

The third fundamental is that the final completed surfacing, regardless of the type adopted or the construction methods followed, should result structurally in the same things, a mat capable of performing its intended function. The selection analysis should be based on the resulting mat rather than on its components or the method of putting them together. A mat, no matter how obtained, has only such maximum load carrying ability as is inherently derived from its component materials, namely aggregate and cement. The method of combination can only affect the degree to which the maximum is realized. If structural analysis indicates a two-inch mat is required, the use of some trick type of construction will not make a one-inch mat do the duty of a two-inch. The purpose of this emphasis on the ultimate structure is that there is too much talk of road mix, plant-mix or penetration types, rather than of flexible versus semi-flexible mats, open versus closed gradings, and similar fundamentals affecting the results obtained from the job.

The previous discussion has been more or less self-evident. It has given the engineer no rules or formula, merely told him to get the best results, with some indication of the logical points to watch. However, from these considerations it is possible to lay down some rules and secondary principles applicable to the selection of the proper bituminous type. They are only general, not in every case true or to be followed.

The first rule is that available local aggregate should be utilized to the logical maximum. The proper utilization of such aggregates is often more talked about than done. The reason is usually a preconceived or arbitrary type selection for which they are obviously unsuited. On the other hand, occasionally in an effort to utilize local products, ultimate economy is sacrificed for apparent immediate benefit, so this phase can be overdone. Generally where local aggregates are not directly the most suitable, a compromise can often be worked out so that neither inferior construction is adopted nor all the material brought in under uneconomical conditions. It is particularly true that the grading or other characteristics of local gravels or soils can often be corrected with a surprisingly small amount of a suitable outside product.

The next point to be made is that regardless of the design followed thereafter, the base should always be penetrated or primed. The reasons for this are technical, as discussed in the author's article on "Cutbacks Versus Road Oils," but may be summed up by the statement that the money expended for priming is more economically used there than in any other possible way. A primed base is desirable to give a greater effective thickness of mat, prevent slip of the mat proper, and to bring about a gradual transition between untreated and treated material, in addition to its obvious waterproofing function.

The third point is that sealing is always indicated for any type adopted if it is not inherent in the type. Such sealing must fulfill the functions discussed in the article on the use of cutbacks versus road oils; it must waterproof as well as strengthen the surface without ultimately reducing the non-skid characteristics. Many types of so-called sealing now being used are of doubtful value in the author's mind; specifically those using materials other than the light naptha cutbacks, generally involving a heavy cover coat of aggregate. This new-layer construction is of questionable sealing value. If the job is too lean, the seal coat merely thickens the mat, covering over the old unsealed condition rather than curing it, hence merely starting a new unsealed surface. If the bitumen quantity is sufficient to really seal the job it is liable to ultimately work up and result in a surface which is far from skid-proof. A treatment using a light naptha cutback in sufficient quantity to properly seal the mat, with enough additional to hold a layer of chips without excess to work up, seems satisfactory, but when sealing a job, care should be taken that that is really what is done.

On other considerations in type selection outright rules cannot be given, but the fundamental principles stated can be resolved into conclusions more immediately applicable. First is the choice between open or closed aggregates. By open aggregate we mean one essentially composed of the larger size particles, or particles which fall roughly in the same size range; by closed aggregates we mean those with a balanced graduation from coarse to fine. Evidently the open type aggregates have large void spaces, while the closed type is relatively low in voids. The desirability of an aggregate depends upon its stability and its void content rather than whether open or closed. The two are sometimes confused due to the fact that open type

aggregates are often crushed materials with high stability, and used for that reason rather than merely because they are open. The supporting power of the mat is a function of the aggregate stability, voids, and the strength of the bituminous cement; strictly all these should be considered in deciding on either the aggregate or the construction. With the same ultimate cementing material available or to be used, a rough tentative rule to offset the strength of one aggregate versus the other would be to use as an index factor the product of the stability times the per cent of non-voids. In other words, an aggregatee of 2500 pounds stability with 40% voids giving an index of 1500 is probably less satisfactory than an aggregate of 2200 pounds stability with 20% voids, with an index of 1760, although the engineer might be attracted by the very stable high void open aggregate's appearance.

Other considerations also come into the picture, in addition to the comparative strength of the two aggregates being compared. The closed type of aggregate usually results in mats which are more flexible or elastic (if well built), also stronger and more enduring, as they get less weathering action due to their close texture. On the other hand the open types are more "fool proof," easier to build to a good job, less subject to water trouble during and after construction. We may indicate the proper choice by the following general statement: If the base is solid, rigid as well as strong, and high stability aggregate is available, the open type is very desirable, provided the ratio of the mat thickness to the largest screen size is not too low, so that the proper interlocking or inherent stability of the aggregate is actually obtained in practice. This type is particularly helpful in cases where water is an additional complication. On the other hand the closed type is usually better under certain conditions, as follows: on strong but less rigid bases; where the usual type aggregate only is available; where aggregate of sufficient stability for use in open type work is available, but can be obtained readily with a balanced grading; and for thin mats. In making this statement it is believed that most secondary considerations such as moisture trouble can be handled through proper design and therefore should not be permitted to too greatly influence the selection of the type. A further corollary of the above general statement is that the open type is quite suitable for wear or armor coats over strong permanent

bases while the closed type is better for supporting mats, that is, for semi-flexible surfaces.

When we come to our next point of considering the choice of penetration versus mixed jobs, definite rules are similarly difficult to lay down but the situation can be to some extent clarified. The usual penetration methods offer less control of the resulting bituminous mixture, but at the same time give a job lower cost. On the other hand, the mixed type of construction is more expensive but susceptible to more accuracy provided the desired control is known. The fact that the per cent of bitumen mixed with the aggregate can be carefully controlled is of no help if the engineer does not know how to properly determine the proper per cent, or to see that it is obtained in the field. Penetration work by some modification can be made self-controlling, which may make it an advantageous as well as a more economical type. In such penetration work a predetermined amount of the bitumen is applied and followed with a controlled amount of aggregate. That is, aggregate is only added in such amounts, over an extended period, to just take up the bitumen applied. The result is a mat of consistent bitumen content, but possibly varying in thickness, instead of a constant thickness but varying bitumen content as will be obtained when a predetermined bitumen application is follower (or preceded) by a set of quantity of cover aggregate. In the author's opinion, this controlled penetration is a very satisfactory method if not used for too heavy a mat.

There are other considerations in comparing penetration versus mixed jobs. In penetration work the job must be smooth to start with if it is to end that way. Usually a penetration job develops with the same contour and same degree of roughness of surface as the base on which it is placed, whereas a mixed job, while best laid on a reasonably smooth base can to a considerable extent even out the base irregularities in the course of construction. In general, in the author's opinion, penetration with controlled cover is desirable where practicable for thin mats, and the mix method for the thicker ones.

Another point that must be considered in the selection of the proper bituminous type is the choice between the stationary and the road mix methods of construction. Note that the location where the mixing is done and the type of equipment used to mix the material are separate considerations. In

other words, road mixing may be done by blades, traveling plant or other similar equipment. Stationary mixing can be similarly done by various types of equipment but in practice is done in a plant located at a suitable point for bringing together the component materials used. Essentially the difference between the two mthods is that in one case the matrials may be uniformly mixed in predetermined proportions at one location with a presumable constancy of conditions, whereas in the other case the mixing must be done on the road and subject to some possible variation.

Practical observations by a number of engineers seem to agree that the theoretical advantages of the plant-mix type in quality of work done are rarely observed in low cost practice. In other words, the appearance and record of success of road-mix jobs is in a general way just about equal to that of plant mix; therefore the decision between the two methods must be primarily based on economic considerations. The reason for plant-mix not seeming to show any great superiority over road-mix when judged by practical results may be one of several. Possibly it is the lack of sufficiently careful operation which goes with low cost practice, and necessarily so if the cost is to stay low. Or possibly the theoretically desirable features of the stationary plant are obtained, but are also obtained in actual fact by the road-mix method. For example, the thorough movement of the mix up and down the road when blades are used tends to even out any variation in the material and give a thoroughly uniform windrow. Also, blading tends to establish a floor, work up any loose base aggregate into the mat and thoroughly oil it, resulting in a job which is well cemented to the primed subgrade without any slip plane from the presence of moisture, dust or similar, such as may occur on plant-mix jobs.

In any event the present conclusion of the majority of state engineers with whom this point has been discussed seems to be that the choice between the two methods must be on the basis of final cost of th satisfactory jobs over an established period of time. These qualifications are essential. The two types, or any types in fact, cannot be fairly established by estimates alone or alternate bids, where one type involves new equipment, methods, etc., with which local contractors are not familiar. The conclusion must be based on full experience with

each type, and in cases of starting a new type, the possibly higher price to be paid on the first few jobs is the cost of pioneering the flexibility which will result from having all suitable types familiar to local contractors. Another point in comparing the two types is that the full picture must be drawn even to the point of maintenance costs. One may appear as good as the other but may cost more to maintain. It is usually thought that the advantage on maintenance will go to the plant job, but that is not always true. Experience shows that both types have advantages as well as disadvantages from the economy standpoint. The plant-mix with heavy oil was unquestionably superior in the days of road oil, but this is questionable now that cutbacks have practically superseded road oils. The real advantages of plant-mix are more indirect, such as the longer working season which may be used when doing plant-mix, possible economies from a central location, and so on. Against all these the advocates of road-mix can point to a generally cheaper cost with more flexibility and the completion of the job with suitability to the immediate needs on each actual station of road. In general no rule can be laid down between the two types but the decision requires careful study and consideration. Furthermore, this study and consideration should always be given, even though there are a number of conflicting elements and pros and cons involved, as on each project there is usually a definite advantage to the adoption of one type or the other.

With the location of the mixing settled, the choice of actual mixing equipment to be used or permitted is too detailed a consideration to be covered in such a general paper. The judging must be on results; equipment is constantly changing and improving and if the mixing is thoroughly done, the resultant job will be the same regardless of how it is accomplished. Attention should be called to the fact that there is no necessary relationship between the cost or complexity of the mixing equipment used and its resulting efficiency. Unquestionably there is intense activity and rapid improvement in efficiency in highway equipment for all types of work, but each proposed method or choice of equipment must be judged on its merits. For example, it is obvious that more efficient mixing can be mechanically done than is accomplished by a battery of patrols. On the other hand, when the blades have pushed and rolled over

the mix a sufficient number of times the highway engineer can be assured the particles are thoroughly coated, the mix well stirred around and uniform, and with everything else satisfactory, the job should be a good one.

Finally there is the effect of the bituminous material on the type selection. There is seldom justification for arbitrarily determining the bitumen to use and picking the type accordingly. The reverse is generally correct, that the type be determined by other factors and the best bitumen to obtain the desired end size. The variation in ultimate strength of mat between good and poor binders is very large, whereas the variation in the ultimate cost of the bitumen is usually a small item in the total cost. If this is not always now so, it will be as soon as the indicated product comes into general use. In the writer's opinion one of the surest signs of insufficient engineering is the failure to determine and use the most efficient bituminous materials.

The decision as to the best bituminous material is susceptible to rational analysis, even more so than the proper type of bituminous treatment to use. The matter has been discussed in detail elsewhere but the principles to be followed in the selection of the proper asphaltic product to be used will be briefly stated. Priming previous to mat construction should be with cutback only. When it comes to the material to use in the mat proper, there is somewhat more freedom, depending on the aggregate and other conditions. However, the general rule may be laid down that road oil hardly pays even in the construction of the mat proper and from a strictly engineering standpoint, is entirely unsuitable in any other place in the best type of construction. Sealing should be done by naphtha cutbacks only in the opinion of the author. On other work the situation depends more on other conditions; water-proofing and soil treatments may utilize road oil without too much disadvantage. In general the principles here involved should be carefully studied. It is believed that they show the reason for the trend to pre-determined cutbacks which in the author's opinion are the only type to consider if the job is to be an engineering one.

In discussing the selection of the proper bituminous surfacing type, attempt has been made to outline general prin-

ciples and give some rules, but the choice primarily requires engineering judgment. The emphasis has been to closely adhere to principles, to carefully determine the functions that the mat must perform, then develop the cheapest type for the purpose rather than overdo definite standardized types. Of course it is realized that standardization is necessary and construction to arbitrary types is better than failure to construct due to an uncertainty as to what to use. Also it is unwise to deviate from well-known standard accepted types unless the individual jobs are really engineered. The main criticism of arbitrary standard types is that they do not always offer maximum economy; also that they are occasionally liable to fail when other construction would probably stand up. It has also been attempted to emphasize that design to overcome known but secondary objection is preferable to letting such secondary objectives influence the choice of type. For example, water trouble in many localities is a serious problem but it is as unwise to adopt unsuitable types to the locality as it is to adopt excessive base or similar construction, when proper design and construction together with suitable bituminous materials would probably overcome the difficulty.

It is firmly believed that if rational determination instead of arbitrary selection of type is adopted as a policy, amplification and clarification of the principles involved will shortly follow. It has been the author's universal experience that in the end rational design, or even only a rational method with its application more qualitative than quantitative, is easier than arbitrary selection which often brings about many perplexing inconsistencies as it is applied from job to job.

Finally in closing this discussion of the selection of the proper bituminous types it is wished to emphasize the same point that has been made on all other technical discussions when involving bituminous treatments: Namely, that low cost roads require high type engineering to produce the desired results.

AVAILABLE TYPES OF ASPHALTIC MATERIALS AND THEIR CHARACTERISTICS IN SERVICE

By C. F. Ramey, Assistant Chief Chemist
Standard Oil Company of California

The earliest use of oil for road purposes in California was by Los Angeles county, in 1898, and by 1900 oil was quite generally used by the counties bordering the San Joaquin Valley. Crude oil of approximately 14° gravity was first used, being distributed from an ordinary water wagon through a perforated spray bar. Prior to application the road surface was not prepared and very little attention was given to its maintenance after treatment. The treatment described was usually sufficient for a season but, due to lack of maintenance after treatment, deterioration of the road progressed according to the nature of the soil and amount of traffic.

The varying stability of the soils treated and lack of proper maintenance caused a very unfavorable reaction toward the use of oil, and the first effort to improve conditions was made by Fresno county. The rough and chucky oil surface was sacrificed, trued up and re-oiled, which prolonged its life and improved the riding qualities as well.

There was no general adoption of this method, although successful oiled road surfaces were constructed in Stanislaus county in 1909, San Bernardino county in 1916 and Riverside county in 1924. Similar work was carried on in the District of Columbia, states of Texas, Colorado, Pennsylvania, New Jersey and many others. Both crude oils and residual oils were employed, with a wide variation of results, and the practice of oiling road surfaces advanced rapidly. During the past five years the progress has been greater than in all the previous history, and the present day technique and practice were established by this early construction.

Asphalt in various forms has been used, including the residual oils and soft asphalt cements frequently made liquid by solution in petroleum distillates and also by emulsifying with water. The present-day treatment utilizes the various grades of liquid asphaltic materials of workable viscosities as binders which may be mixed with the mineral aggregate directly on the road or at a central mixing plant. Either process will permit the most economical use of local materials.

Liquid asphaltic road materials of satisfactory quality have all the requisites of good binding materials for the mineral aggregates which furnish the stability and abrasive resistance of road surfaces. Since they are relatively inexpensive, these binders occupy a position of special importance in the field of low-cost construction of durable roads.

In the past the term "road oil" has been used in describing these materials, but this term is not sufficiently descriptive and the loose manner in which it is used leads to confusion. It has been applied indiscriminately to materials ranging from naptha cut-backs to residual oils and even to crude petroleum, as well as materials ranging from liquids of low viscosity to semi-solid asphalt.

The old idea of one product for every and any condition is obsolete and, for the present at least, the procedure followed is to use a form of asphalt designed to meet a definite condition, in order to assure the most permanent results and the greatest of application. This has resulted in the development of all necessary types of liquid asphaltic materials, keeping in mind certain characteristic factors as:

1. The consistency of the asphaltic material when received from the refinery.
2. The period of time elapsing between application of the asphaltic material and the attainment of its final consistency.
3. The final consistency at completion of the job.
4. The length of time the material retains its final consistency, which is, to a certain extent, a measure of its ability to sustain traffic.

The time of setting, or of developing the asphalt cement, is further modified by the character of the aggregate or road surface, in general being hastened by the presence of dust or very fine particles. This particular characteristic is to be taken into consideration when selecting the proper grade of asphaltic product for a particular kind of road surface.

Asphalts, residual oils and distillates (cutter stocks) used in the manufacture of liquid asphaltic materials are products of distillation in the refining of petroleum. The distillation of

petroleum is founded on a very simple process, a well-known example of which is that observed in the boiling of a tea kettle, with the difference, however, that when the vapors or steam is passed through a pipe and cooled it will collect or condense as water—the original substance—whereas the hot vapors of petroleum, which separate according to their volatility, when cooled form different products known as gasoline, kerosene, etc. In other words, the basis of refining of petroleum is elimination and fractionating, elimination of certain portions and the segregation of others, in accordance with their respective ranges of boiling points. Products so produced are then blended or fluxed in the preparation of the finished materials; in the case of true cutback asphalts, the asphalt cement is fluxed to any desired viscosity with their essential characteristics as rapid-curing, medium-curing and slow-curing—depending upon the degree and rapidity of hardening which takes place after use.

Three classes of materials cover all necessary grades:

Rapid Curing Cutback Asphalts

Naptha cutback asphalts are designated as "RC MATERIALS."

Medium Curing Cutback Asphalts

Kerosene cutback asphalts are designated as "MC MATERIALS."

The asphaltic oils widely used on the Pacific coast in highway construction are designated as "SC" or SLOW CURING PRODUCTS.

The specifications for these products contain three fundamental determinations for the classification of liquid asphaltic materials, these being:

Viscosity Test, which determines the degree of fluidity of the original at a definite temperature and affords an indication of the suitability of the product from the standpoint of application for the particular type of construction or maintenance in which it is to be used;

Distillation Test, which indicates the quantity and character of lighter constituents which may be expected to be eliminated through volatilization or absorbed during application and early use of the material;

Consistency of Residue After Distillation, which indicates the probable extent of curing and the character of the asphaltic

material retained by the mineral aggregate in the highway after completion of the construction.

Liquid asphaltic road materials have, then, been developed and made available for a variety of purposes in the treatment, construction and maintenance of highways. The characteristics which the material should possess will vary to a marked degree, dependent on the purpose for which it is to be used, the character of the mineral aggregate, time in which it is expected to harden and the character of the final hardened product. The most satisfactory range in original viscosity of the three classes of liquid asphaltic materials is determined by the type of treatment or construction and the condition under which it is to be applied and manipulated. For this reason each class is sub-divided into appropriate grades defined by viscosity limits.

The principal use of these road materials, with reference to the class found most satisfactory, can be subdivided into Surface Treatment and Admixtures. With reference to surface treatment slow curing products are used as dust layers, medium curing products as primers, rapid curing products as carpet builders. With reference to admixtures, rapid curing products are used with coarse, open aggregates, medium curing and slow curing products are used with dense graded aggregates.

A primer is used in the preparation of an existing road surface in order to make it adaptable for additional treatment. Primers are mainly used on waterbound types of surface such as earth, sand, clay, gravel and macadam. For this reason a primer should be of low viscosity, thereby being readily and completely absorbed by the surface, after which it should harden and thus consolidate and assist in waterproofing the surface. Although acting as a dust layer for dust which may be present, a primer is not essentially a dust-laying oil and further should not be expected to serve as a binder for aggregate cover that may be applied later. A slow-curing or residual oil is more satisfactory for use as a dust layer, and a more viscous cutback asphalt is to be preferred for use as a binder for cover aggregates.

Where the purpose of surface treatment is to build up a thin waterproof bituminous carpet course the material is a rapid-curing cutback asphalt of somewhat higher viscosity than dust layers and primers, but yet sufficiently low to permit ap-

plication under pressure with little or no preheating. Shortly after application it will develop into an asphalt cement of high bonding strength and thus hold a cover coat of mineral aggregate which will not be readily displaced by traffic.

Rapid-curing products are used in open aggregate mixtures such as the macadam type where it is necessary that each fragment be surrounded by a thick film of asphalt in order to produce a firm, durable bond. This is best secured with a product of sufficiently high original viscosity as can be manipulated and the asphalt that develops from volatilization of the cutter stock should have the consistency of a paving grade of asphalt cement.

For dense graded aggregate mixtures which contain an appreciable percentage of 200-mesh particles the use of medium curing or kerosene cutback materials appears desirable. This material should have a viscosity that will prevent its displacement by waters of precipitation or capillary moisture coming up through the subgrade. After compaction usually effected by traffic, the medium curing cutback at the surface quickly hardens to a soft asphalt cement to produce a waterproof seal. The curing process below the surface is much more gradual, and this is a very desirable feature for aggregates sufficiently dense to produce a good waterbound road, even without a bituminous binder. In much of this type of construction slow curing products have been used with satisfactory results.

The rapid curing cutback asphalts are blended to the desired viscosity using approximately 80 penetration asphalt cement, and a naptha cutter stock having a distillation range of approximately 275°F. to 450°F. They are typical rapid curing products when distilled to 680°F. they yield asphalt cement, and the fact that approximately one-half of the total cutter stock distills before 437°F. indicates that these materials were produced by fluxing asphalt cement with a naphtha type of cutter stock. These materials have rapid drying properties similar to quick drying paints and can be used where it is desired to develop a strong asphaltic bond as quickly as possible after application.

Type RC-1. A rapid curing liquid product containing approximately 35% of naphtha cutter stock of low initial viscosity (80/160 at 122°F. Say. F.) suitable for surface treatment and re-treatment as seal coat, or in the construction of

thin bituminous carpet courses with a light cover of suitable mineral aggregate free from dust.

Type RC-2. A rapid curing liquid product containing approximately 26% of naphtha cutter stock of relatively low viscosity (200/400 at 122° F. Say F.) suitable for the preparation of cold patch mixtures with open graded mineral aggregate having little or no material passing the 10-mesh and practically none passing the 200-mesh sieve.

Type RC-3. A rapid curing product containing approximately 20% of naphtha cutter stock of medium viscosity (275 /400 at 140°F. Say. F.) suitable for use in the construction of roller-compacted road mix wearing courses or cold patch mixtures in which the mineral aggregate is of the open type, consisting principally of crushed fragments, maximum sizes not over 1½″ and practically all of which is retained on a ¼″ screen.

Type RC-4. A rapid curing product containing approximately 15% of naphtha cutter stock of high viscosity (700 /1400 at 140°F. Say F.) suitable for use in plant mix construction of wearing courses which are to be roller-compacted, and in which the mineral aggregate is of the open type consisting principally of crushed fragments, maximum sixe not over 1½″ practically all of which is retained on a ¼″ screen. It is particularly adapted for use under conditions where the mixture is to be laid and compacted immediately after mixing.

This product may also be used for seal coat treatment work on old bituminous or well compacted non-bituminous base courses where an exceptionally quick setting binder of high viscosity is desired.

The medium curing cutback asphalts are blended to the desired viscosity using approximately 110 penetration asphalt cement and kerosene cutter stock having a distillation range of approximately 350°F. to 550°F. They are typical medium curing products and in turn yield a residue from distillation to 680°F., which is an asphalt cement, but because the proportion of cutter stock distilled at 437°F. constitutes only a relatively small proportion of the total cutter stock its curing properties are not as rapid as the "RC" materials. These materials may be compared with a slow drying paint and such products are suitable for use under conditions where the immediate develop-

ment of a strong asphaltic bond is not needed, but where a marked increase in viscosity is required shortly after application.

Type MC-1. A liquid product containing approximately 46% of kerosene cutter stock of a very low viscosity (40/150 at 770°F. Say. F.) for cold application, suitable for use as a primer for initial surface treatment of road surfaces prior to construction of a bituminous wearing surface. This priming material is readily and completely absorbed by earth, gravel, or broken stone surfaces and it hardens in place. It develops considerable cementitiousness upon drying, but it is not intended to hold a cover of stone chips or gravel.

Type MC-2. A medium curing liquid produce containing approximately 27% of kerosene cutter stock of low viscosity (150/250 at 140°F. Say F.) for use in the construction of traffic compacted road mix wearing surfaces in which densely graded mineral aggregate is used having a maximum density of 1″ and with 35 to 60 per cent of the material passing a 10-mesh sieve, and 7 to 14 per cent passing a 200-mesh sieve. MC-2 should ordinarily be warmed before application. Its viscosity materially increases after use, and it develops considerable cementitiousness.

Type MC-3. A medium curing liquid product containing approximately 21% of kerosene cutter stock of medium viscosity (300/500 at 140°F. Say. F.) suitable for use in the construction of cold laid plant mix wearing surfaces which are to be compacted by traffic or, in warm weather, for mixed-in-place wearing surfaces in which the mineral aggregate is densely graded from 1″ to dust with from 35 to 60 per cent passing a 10-mesh sieve, and from 7 to 14 per cent passing a 200-mesh sieve. It is also desirable for use in the construction of roller-compacted road mix wearing surfaces in which the mineral aggregate is of the open graded type having a maximum density of not over 1″ and containing little or no 200-mesh material, but having a relatively high percentage passing the 10-mesh sieve.

Type MC-4. A medium curing liquid product containing approximately 17% of kerosene cutter stock of relatively high viscosity (500/800 at 140°F. Say. F.) designated for use in the construction of roller-compacted cold laid plant mix wearing surfaces, or in hot weather for road mix wearing surfaces. In either case the mineral aggregate should consist of relatively

open-graded broken stone or gravel with a maximum diameter of about 1″ and should contail little or no material passing the 200-mesh sieve, but should have at least 35 per cent passing the 10-mesh sieve. The MC-4, and sometimes the aggregate, should be warmed before mixing.

Type MC-5. A medium curing product containing approximately 14% of kerosene cutter stock of high viscosity (170/280 at 180° F. Say. F.). It is suitable for use in the construction of cold laid plant mix wearing surfaces which are to be roller-compacted, and in which the mineral aggregate is of the open graded type having a maximum diameter of 1″ and containing practically no material passing the 200-mesh sieve, but with an appreciable percentage passing the ¼″ screen. For the above type of construction the MC-5 and usually the mineral aggregate will require heating. MC-5 is also suitable for use with heated aggregates consisting of densely graded broken stone or gravel containing from 35 to 60 per cent of material passing a 10-mesh sieve, and which may contain a small percentage passing the 200-mesh sieve. With this type of construction it may be subjected to relatively heavy traffic and severe climatic conditions.

The slow curing products are residual oils of specified viscosity range. No cutter stock is used, and for this reason these materials are not classifiable as cutback asphalts, but should be considered purely as slow curing products. The SC materials when distilled to 680°F., do not yield asphalt cements, but a highly viscous residue. As a matter of fact the initial boiling point of these materials may be 500°F., or greater, and in most cases, particularly for the heavier grades (SC-2, SC-3 and SC-4), very little distillate is obtained even at a temperature of 680°F. These slow curing products have been successfully used under certain conditions where high bonding strength is essential.

Type SC-1. An asphaltic oil of very low viscosity (20/40 at 77°F. Say. F.) suitable for cold application as a dust palliative. It may also be used in the initial treatments in the progressive method of mat construction on soils or sands where gradual improvement is to extend over a number of years with subsequent treatments employing heavier types of asphaltic road materials. This product is not intended to serve as a hardening or cementing medium. It corresponds to and replaces the former "30-35 Asphaltic Oil."

Type SC-1A. An asphaltic oil of comparatively low viscosity (40/80 at 122°F. Say. F.) largely used on the Pacific coast where a priming material or dust palliative having a small amount of cementitiousness is desired. It replaces similar products formerly sold on the Pacific coast under the designation of "50-60 Road Oil." Its comparatively low cementitiousness makes it unsuitable for use as a cementing medium for the construction of road mix or plant mix wearing surfaces. It has been frequently used as a primer on waterbound macadam or gravel surfaces prior to the construction of a thin bituminous surface of the "Armor Coat" type, but asphaltic road material MC-1 is now recommended for this purpose.

Type SC-2. A very slow curing liquid asphalt product of low viscosity (200/300 at 122°F. Say. F.) formerly designated in the Pacific coast region as 65 plus road oil. It is suitable for use in relatively dry climates for the construction of traffic-compacted road mix wearing surfaces with densely graded mineral aggregate ranging from a maximum diameter of 1″ with from 35 to 60 per cent passing a 10-mesh sieve, and from 7 to 14 per cent passing a 200-mesh sieve. It can be readily mixed during cool weather and should ordinarily be warmed before application. This material may also be used in "blotter" treatment of clay roads with a loose cover of fine gravel aggregate. It is also widely used on the Pacific coast in the preparation of airport runway surfaces.

Type SC-3. A slightly heavier slow-curing asphaltic oil of medium viscosity (150/200 at 140°F. Say. F.) suitable for road mix work in dry climates during hot weather where such wearing surfaces will be compacted by traffic and in which the mineral aggregate is densely graded from about 1″ to dust with from 35 to 60 per cent of material passing a 10-mesh sieve, and up to 14 per cent passing a 200-mesh sieve. It requires warming before application. This material was formerly designated on the Pacific coast as "70-80 Road Oil."

Type SC-4. A very slow curing asphaltic roid oil of high viscosity (350/550 at 140°F. Say. F.) suitable for use in dry climates in the construction of cold laid traffic-compounded plant mix wearing courses in which the mineral aggregate is densely graded from a maximum diameter of about 1″ down, with from 35 to 60 per cent passing a 10-mesh sieve, and from

7 to 14 per cent passing a 200-mesh sieve. The asphaltic material, and generally the aggregate, requires heating before mixing.

Asphaltic Road Material 95 Plus. This material is the heaviest grade of slow curing road oil and has a very high viscosity (250 min. float at 122°F.). It is suitable for use as a binder material in the construction of bituminous macadam pavements of the penetration type or for use as the binder in bituminous surface treatment work of the "Armor Coat" type, as well as in seal coat and non-skid surface treatment.

It should be understood that all three classes of products can be readily produced of any desired range of viscosity, and such ranges have been established and the basic specifications for these materials issued by the U. S. Bureau of Public Roads as well as the Asphalt Institute. The liquid asphaltic materials discussed are manufactured or blended in a similar manner by all the major producers in the Western area and are supplied on these basic specifications.

It might be of interest at this time to call your attentior to certain additional items that are being added to specifications describing asphaltic material in some of the Eastern and Middle-Western states. These special requirements are high sulfur in excess of 3% ductility at low temperatures, fluidity factor, susceptibility factor and spot test. With the exceptior of the spot test, these special requirements are, in my mind, quite restrictive and purely source-identifying, with particular reference to the geographical source of the asphaltic material. Although there are some domestic crudes from which high sulfur asphaltic material can be produced, this requirement seems definitely to require the use of Mexican crudes, and there is no supporting data that indicates any beneficial effect from the use of high sulfur asphaltic materials.

The necessity of ductility at low temperatures has not been definitely established as a necessary characteristic since, insofar as asphaltic materials from California crudes are concerned, satisfactory service has been and is still being given by products which have no measurable ductility at low temperatures as determined by the standard test method.

The fluidity factor is an arbitrary figure based on the relationship of Furol viscosity at 275°F. and penetration at

77° F. and apparently is based on materials from Mexican crude. The significance of this test is very questionable since materials from California crudes will fail to meet the fluidity factor of 140 as required in certain specifications, and these same materials have been and are still being used satisfactorily in construction and maintenance work.

It should be recognized that the tests taken on asphaltic materials at the present time are primarily for the purpose of checking the purity and uniform quality of the product, there being no correlation between these tests and the practical use of the material. This statement is made for the reason that tests are conducted on a mass of material while in the pavement it exists in thin films, and it is a well established fact that materials in thin films do not exhibit the same characteristics as the same materials in mass. It is our feeling that tests such as these have no part in specifications because of their restrictive nature and the fact that they really are source-identifying tests.

Of the tests referred to, the Oliensis spot test may be of interest or value for the reason that it can be applied on asphaltic products from any source and identifies not the geographical source of the product, but indicates a specific condition that has been produced in the refining process. It does afford a means of differentiating between a cracked and a normal steam refined asphaltic product. If it is the intention of the engineers to use only a normal steam refined or vacuum-produced product, this test may be used as a guide, but it should be understood that no claim is made that this test indicates whether or not a normal steam refined product or a cracked product is of better or poorer quality. It has been stated by various authorities, however, that in practical work a greater quantity of cracked product is required than of the normal steam refined product.

In closing, I might state that both residual oils and cutback asphalts are now being utilized to a great extent for bituminous mats of asphaltic type, with a decided trend toward the use of cutback asphalts.

PRACTICAL APPLICATION OF ASPHALTIC MATERIALS WITH PREPARED AGGREGATES.

Presiding, Tom Perry, Bituminous Engineer
Iowa Highway Commission.

MODERN PRACTICE IN BITUMINOUS SURFACE TREATMENTS

Paper Prepared by I. E. Russell, Materials Engineer, Wyoming State Highway Department, and Presented by J. R. Phillips, District Engineer, Wyoming State Highway Dept.

At the beginning of 1927 Wyoming had exactly 53 miles of highway with surfaces of a type higher than gravel. Today, nine years later, there is a total of 2,512 miles of paved surfaces with, of course, the various types of oil mats predominating. This is an enviable record especially in view of the fact that a large part of that mileage had to be built from the ground up. The total available construction fund for this period averaged approximately $2,260,000 dollars per year, and when one drives over these miles of improved highways today it is very apparent that the taxpayers' dollars have neither been wasted nor unwisely spent.

With some 1500 miles of unimproved road to be graded, 700 miles of graded road to be surfaced and 900 miles of surfaced roads to be properly maintained, the Highway Commission was indeed faced with a serious problem. A careful study of the situation brought out recommendations whereby the entire system could be built to the gravel surface standard over a period of ten years. Funds were provided by the Legislature and the construction program was carried on as planned.

With the volume and the speed of traffic steadily increasing, the problem of maintaining the surfaces had to be solved immediately if the capital investment were to be conserved. The maintenance alone, without considering replacements which in many cases would have called for one inch of gravel per year, was enough to threaten the financial set-up for further

construction. It was practically impossible to maintain the gravel surfaces in anything like a satisfactory condition. Even the leisurely Sunday drive in the family car was fast becoming more of a hazard than a pleasure.

Experiments the previous year (1926) with a light treatment of gravel surfaces using residual oil had given some promise of relief and it was accordingly decided to pursue this program with the thought in mind of reducing maintenance costs and conserving the road metal. Without any doubt, this decision resulted in the writing of the most important chapter in the history of Wyoming roads.

At the end of that year 87 miles of gravel road had been treated with an asphaltic oil. The excellent results derived, augmented by the insistent demands of the public, have, of course, been the means of bringing about the fine system of highways which today form a network over the entire state.

The earliest experiments in treating gravel with oil were far from satisfactory due largely to the type of oil used and a misconception of what was to be expected of the treated surface. At first there was no intention of obtaining a solid mat but rather a mulch surface which could be manipulated and smoothed with blade graders. A light fuel oil of paraffin or semi-paraffin base was used and instead of forming a mulch, as expected, it developed a mat on the surface. Due, however, to the lack of binding power of the oil, this mat broke up badly forming ruts and holes, resulting in a surface that was impossible to properly maintain. The treatment was accomplished by spreading the oil on the lose gravel surface and lightly mixing with blade graders. Re-oiling with the same type of oil failed to improve conditions.

Further investigation developed the fact that only a pure asphaltic base oil would produce reliable results. A specification was therefore adopted for the 1927 requirements calling for such an oil having an 80 penetration residue of from 60% to 75% and a viscosity (Engler) at 122°F. of 25 to 45. This specification was later changed to permit of higher viscosity and in 1933 the present set of specifications covering slow, medium and rapid curing liquid asphalts was adopted.

Of the total mileage of bituminized surfaces in Wyoming 325 miles are of the plant mixed type, 1,640 miles are of the road mixed type and 515 miles are of a type which might better

be classified as surface treatments. The plant mix is definitely without the scope of this paper and will not be discussed. However, in view of the fact that methods employed in the construction of certain types of surface treatments encroach upon those of the road mix, it will be necessary to discuss this type briefly in order to fully cover the field of surface treatments.

Surface treatments as built in Wyoming, when considered as all types other than strictly plant and road mix, should properly include base stabilizations, light penetration or blotter treatments, penetration macadams, plain seal coats without cover and stone chip or non-skid seal coats.

Base Stabilization or Thin Road Mix

When the state first embarked upon the program of bituminous treatments the Bureau of Public Roads required a section or thickness of not less than six inches, that is to say, three inches of base course gravel and three inches of oil mixed surface. Federal funds were apportioned so far as possible and the projects were built in accordance with the road mix type of construction. The road mix cost approximately $1,850 per mile in addition to the cost of gravel necessary to bring the section to the proper thickness. It was apparent that the funds available would not permit of sufficient mileage at that cost. With some 900 miles of roads already surfaced and still having from four to six inches of gravel in place it was decided to make use of state funds to push forward a program of lighter treatments designated as base stabilizations. This would permit of a breathing spell so to speak and give the Highway Commission a chance to catch up with the future construction program.

For this type of construction, projects were chosen that had at least four inches of gravel surfacing remaining. Windrows were bladed to the side of the road sufficient in size to assure a compacted oil mat of at least 1½ inches. Wherever possible,, scarifying of the surface was avoided so as not to disturb the base.

The base was then primed with a light residual oil having from fifty to sixty per cent of one hundred penetration asphalt. When this had penetrated and dried sufficiently the windrow was spread over the road surface, treated with 65 grade of road oil, mixed with blade graders and spread to the proper crown and section. Compaction was at first secured

through traffic only and careful maintenance was necessary until the road surface had set up firm and smooth. This final maintenance was very essential to prevent the formation of traffic ruts. Later it was found of advantage to roll the surface with a light roller and thus eliminate to a large extent the necessity of the final maintenance.

This type of construction cost on an average approximately $1,250 per mile and where subgrade and drainage conditions were favorable very satisfactory results were obtained.

Practically the same type of treatment has been applied the past season to 87 miles of secondary highways, the only change of importance being in the types of asphaltic materials used. MC-1 was used as a prime coat and MC-2 and MC-3 for the mixing. The Bureau of Public Roads participated in this construction with the understanding that the state adequately maintain the surface and increase the thickness of the mat if and when consitions required that this be done. For the past few years most of the mixing has been done with traveling road mix machines. The average cost using the cutback asphalts in place of residual oils was $1,650 per mile and without question this additional cost has been fully warranted.

A total of 196 miles have been built to date in accordance with this base stabilization method and results, when viewed in the light of servicability and cost of maintenance, prove this type to be the most practical and satisfactory surface treatment.

Light Penetration or Blotter Treatments

Light penetration treatments have been applied to 240 miles of surface. Due to the methods employed in this type of construction it must of necessity be confined to crushed rock or tightly bound gravel bases.

The entire mileage of this type of surface was built by state forces. For some time prior to actual treatment, the maintenance forces were instructed to blade the surface of the project, when conditions were right, carrying the windrow thus developed to the side of the road. In no case were they permitted to scarify the surface in order to obtain the necessary windrow.

When sufficient material to afford a light cover coat had been set aside, the surface of the road was thoroughly swept with a power sweeper. The surface was then treated or primed with a light residual oil or, more recently, with MC-1 cutback.

After this had thoroughly dried an application of from 3/10 to 5/10 gallon per square yard, depending upon the amount of cover material, of RC-2 cutback was applied to the surface and the windrow of cover material immediately spread over it by means of a blade. There being no further manipulation the road was immediately opened to traffic. In the more recent work of this type rolling followed immediately after the application of the cover material resulting in a better bonded surface and little or no loss of cover material.

The success of this type depends entirely on the condition of the base and even when this is substantial, the mat developed is not thick enough to withstand severe traffic without constant care. One section has been under service on the Lincoln Highway for three years and has given service adequate for the money spent, but resurfacing will soon be necessary. Maintenance presents a problem in that it must, of necessity, be done entirely by hand methods. This type can scarcely be recommended except as an expedient or on such sections as will not carry heavy traffic. It could be greatly improved if new material in the form of dustless stone chips were provided instead of blading the cover coat material from the road surface. Stone chips cast over the asphalt evenly by means of mechanical spreaders would also present a much better non-skid surface.

These light penetration types cost on an average of $1,000 per mile. They were built as an expedient to conserve the surfacing material in place and to extend quickly the mileage of dustless bituminized surfaces, with the full understanding that they would sooner or later have to be resurfaced. The thin road mixes have proven more satisfactory and have supplanted this type of construction.

Penetration Macadam

These types are by far the most expensive of the surface treatments costing approximately $17,000 per mile of twenty foot road for a two inch thickness of mat on a four inch crushed rock base. Due to this high cost, macadam surfaces have been confined entirely to municipal project for which funds were made available by the Federal Government during the 1934 construction season. Sixteen miles were constructed at an average total cost per mile, including grading and draining, of $23,500. A comparison of the cost of this type with that of

9″-6″-9″ concrete pavement, of which six miles were built within cities the same year, shows the concrete to be only $7,000 more per mile.

A brief description of the materials used and the construction methods for the macadam surface and the base course upon which this type was laid may be of some interest.

The crusher run base courses were built of crushed limestone graded so that it all passed a 2½″ circular opening and was well graded from that to ¼″. It was required that from 50 to 70% must be retained on the ¼″ sieve. The portion below ¼″ consisted of rock screenings and not more than 10% of the total material was permitted to pass the 200-mesh sieve.

Particular care was taken to insure, as nearly as possible, a uniform density of the subgrade throughout its entire width. This was of decided importance as a preventative measure against future settling and the attendant irregularities of the finished surface. Satisfactory results were obtained by scarifying to a depth of six inches, reshaping and rolling. All rolling was accomplished by the use of self propelled rollers of ten ton capacity.

Wherever the thickness of the base was four inches or less the specifications permitted all of the crushed rock to be placed in one course. After being placed on the grade, the rock was sprinkled with water and thoroughly mixed by blading, spread to section and rolled. The completed base, with a firm, even surface, conformed to the grade set for the bottom of the proposed macadam wearing surface.

The specification for the macadam top required three sizes of rock, that is, coarse rock graded from 2″ to 1″, key rock graded from ¾″ to ½″ and stone chips from ½″ to ⅛″ all produced from sound ledge rock only. It was required that the rock be well graded from coarse to fine within the limits set for each size and the percentage of wear was restricted to an upper limit of 8 per cent. Bituminous binder consisted of 95 asphaltic road oil and MC-1 was used as a prime or tack coat.

The surface of the base course was swept with brooms until the larger stones were exposed and the upper interstices opened so as to secure a mechanical bond with the wearing course. MC-1 cutback asphalt was applied at the rate of ¼ gallons per square yard of surface and when this had dried sufficiently the coarse stone was spread over the base, shaped

and rolled until it presented a firm even surface. After this rolling, the surface was checked with a template and variations greater than ¼″ were corrected and the surface re-rolled. Particular care was exercised to obtain a true surface at this stage since defects would be carried through to the final surface.

The first application of bituminous binder was then made and allowed to stand for twenty-four hours. A thin layer of key rock, sufficient to cover the surface and prevent pick up, was then applied and the surface lightly rolled. Additional key rock was then placed and spread carefully to shape and crown and the surface rolled thoroughly until it was smooth and tightly packed.

The surface was then examined for localized areas showing material finer than key rock. If any were found the material was removed, replaced with clean key rock and again rolled. A second application of bituminous binder was then made and followed by a uniform spread of stone chips sufficient to prevent pickup during subsequent rolling. Final rolling was then required until a smooth, hard finished surface was obtained.

The road was then opened to traffic for a period of from two to four weeks. The final application of binder was then spread, followed by stone chips sufficient to take up the binder. Final rolling then completed the work. Average quantities per square yard of materials used on the macadam projects were as follows: MC-1 cutback asphalt for prime or tack coat, one quarter gallon; coarse rock 180 pounds; first application of binder 0.8 gallon; key rock 26 pounds; second application of binder 0.4 gallon; stone chips 32 pounds, and final application of binder 0.25. These quantities were based on a two-inch compacted wearing course.

This type of penetration macadam unquestionably produces an excellent surface and its cost is fully warranted for areas of concentrated and heavy traffic. Macadams, in Wyoming, will be confined to such areas, especially since it has been learned that a comparable type can be built using a well graded crushed rock with an RC-3 cutback. This type can readily be mixed on the road with either a retread paver or traveling plant and at a cost much lower than the penetration type. Two such projects have been built, one using rock graded from 2″ to ½″ with all fines eliminated, the other with crusher run limestone graded from one inch to dust. The average grading of the material on the latter project showed 25 per cent passing

the 10-mesh sieve with four per cent passing the 200-mesh sieve. No difficulty was experienced in mixing this material with a Barber-Green traveling plant. Excellent results were obtained on both projects.

Plain Seal Coats Without Cover

Experience with road and plant mix projects has demonstrated that mixes which are slightly lean give better results from the standpoint of stability. With even fairly rich mixes, however, the asphaltic oil tends to oxidize and the surface of the road eventually turns a brownish color and dries out. This permits the infiltration of water and the surface is quite likely to ravel. This condition naturally occurs more quickly with the lean mixed surfaces so all contracts for these types carry a provision for sealing immediately after all other work has been completed.

Sealing was at first done with a sixty grade of residual asphaltic oil, but for the past several years RC-1 cutback asphalt has been used. This material as specified differs from the generally accepted specification only in the penetration of residue from distillation, the limits being from 60 to 80.

The cutback is applied to the bituminous wearing surface by means of pressure distributors at from 1200 to 1500 gallons per mile of 20-foot road. One half of the roadway is treated at a time and traffic is carried through on the other side. Where conditions warrant, the traffic is handled by means of a pilot car otherwise by flagmen only. Travel in one direction only at a time is permitted. The cutback applied one day is safe to travel the next day. Experiments have been made the past season with a slightly modified type of cutback which is expected to materially reduce the time necessary for drying. Apparently this material is more satisfactory, but a change in specifications will not be made until investigations have been completed next spring.

This plain type of seal coat without cover costs on an average $125 per mile of completed work. It usually is necessary to reseal the surface within three years, but even so, the money is well spent. Practically every mile of road and plant mix has had at least one seal of this type. Most of the resealing has been done by the maintenance crews although in a few instances, where it was necessary to treat a large mileage in the same section of the state, the work has been contracted.

Stone Chip or Non-Skid Seal

The stone chips seal has been applied to 178 miles of bituminous wearing courses throughout the state. It is of a much higher type than the plain seal and has the added advantages of giving longer service, of improving night driving conditions, of strengthening the surface mat and of producing a non-skid surface.

Approximately 100 tons of stone chips per mile of road were used for this type of seal and it was evident that a crushing and screening plant which could be easily moved from one pit to another would be necessary. In order to reduce haul, stock piles averaging about 2,500 tons had to be produced at convenient locations along the road to be treated. Contract prices for stone chips were prohibitive and it was therefore decided to purchase a crushing and screening plant and produce the material, using state forces.

The plant purchased was a Diamond weighing 4,900 lbs. and mounted on six pairs of pneumatic tires. It was equipped with an 8″x36″ jaw crusher and 22″x18″ rolls with double deck vibrator screen for returning oversize to the crusher and rejecting the fines developed in the crushing process. It also was equipped with an auxiliary double deck vibrator screen for rejecting all fines before the pit material reached the crusher.

Operating in thirteen different pits at widely separated points over the state, this plant produced 29,692 tons of stone chips at a cost of $1.30 per ton. During the time the plant was in operation there was also produced 10,243 tons of ⅝ to 1¼″ rock for patching purposes at a cost of $1.11 per ton and 24,543 tons of gravel surfacing at $0.48 per ton.

The stone chips were produced in such manner that all passed a ¾″ sieve, from 90% to 100% passed a ½″ sieve and not more than 5% passed a number 8 sieve. RC-2 cutback asphalt was used to bind the chips to the surface.

The surface of the wearing course was swept clean and ¼ gallon of cutback per square yard of surface was applied with pressure distributors. This was immediately followed by an application of stone chips at the rate of 18 pounds per square yard. The chips were spread with a desk type mechanical spreader. Uneven spots were smoothed by hand spreading and sweeping and the surface was then rolled. The specifications required a roller having 190 to 270 pounds compression per lineal

inch on the compression roll. Rolling was confined to the minimum necessary to set the stone chips and prevent their loss. Where detours could not be provided economically, one-half of the road was treated at a time and traffic flagged through on the other half.

Most of this work was done by maintenance forces. With an average haul of about five miles, a crew of nine men consisting of two oil distributors, one spreader, four truck drivers and two flagmen completed a mile of road per day. Rolling was handled by one of the distributor men. The total cost averaged $640 per mile of completed work. Contract prices have averaged $900 per mile, but this price would very likely be considerably reduced if contracts involving considerable mileage were awarded. With costs this high, it is apparent that stone chip seal coats should be placed only on those surfaces which are not at all likely to fail from other causes. The benefits derived seem to justify the costs involved in this type of seal.

Conclusions

Base stabilizations or thin mat road mixes have definitely established their value. They will carry without excessive maintenance costs, a fairly heavy traffic. Cutback asphalt of the MC-3 grade when used for this type, results in a stronger, better bonded mat and without doubt the additional cost is justified.

Light penetration or blotter treatments have their place in a bituminous construction program only where it is expedient to temporarily extend the mileage. Replacements will rapidly become necessary and maintenance costs are too high. Thin road mixes can be built at approximately the same cost and results are far more satisfactory.

Penetration macadams are excellent pavements but their cost restricts them to heavy traffic areas. Road mixes using crushed rock and the heavier RC cutback are quite likely to supplant this type entirely.

Plain seal coats are essential in any bituminous program. They form a barrier between high and low maintenance costs and the ease with which they may be applied, either through contract or by maintenance crews, coupled with their low cost, as compared to the benefits derived, make them indispensable.

Stone chip seal coats lighten the road surface and vastly improve night driving conditions. For this reason alone, they have been warmly received by the public. The benefits derived most assuredly justify the expenditure for this type of seal and the mileage will be extended in Wyoming as funds become available.

The people of the state are well pleased with the progress made in bituminous surface treatments of all kinds and with the highway system so nearly completed it will very likely be only a short time until funds will be available to bring all of these surfaces up to the very latest standards both as to width and type of wearing course. Without question, the bituminous treatment of road surfaces has been the one and only possible answer to the problem not only in Wyoming, but in the other Rocky Mountain states as well. All of these states can well be proud of the records they have made with the limited funds available.

MODERN PRACTICE IN ROAD MIX

By Levi Muir, Materials Engineer
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The previous papers have covered very fully the soils and subgrade, foundations above the subgrade, selections of the surface materials and the bituminous binder, so important to the construction of satisfactory bituminous surfaces. This paper will deal with construction of the close graded aggregate type of road mix surface.

Before entering into a discussion of the different methods of mixing, it might be well to give some idea of the plans and controls as used in Utah. Present plans provide for a 20-ft. width of oil mat, having a thickness of three inches when compacted. We also require a thickened edge. The outer two feet of mat vary from 3 inches to 5 inches in thickness. A 2½ inch crown has been adopted as a standard.

The thickness of sub-base gravel required averages about 10 inches under good conditions. More is used where poor soil and drainage conditions are encountered.

Present specifications provide for the use of SC-3 road oil. This heavy road oil serves very well except for late season work where the cold weather causes difficulty in mixing. For

early spring and fall work we have frequently changed to SC-2. In earlier constructions we have used a lighter road oil than the SC-2 and it has given seven years of satisfactory service. All oil used is carefully checked for compliance to specifications in the chemical laboratory.

Material Tests and Control

In all oiling we maintain a very accurate control of the amount of oil added to the gravel. Laboratory and field tests enable us to predetermine the correct mix for obtaining the best results.

It is absolutely necessary that all material above the subgrade soil be granular and nearly constant in volume. In Utah that part of the gravel smaller than No. 10 mesh must be either an A-1, A-2 or A-3 soil. Field moisture equivalent and linear shrinkage tests are made on all materials entering gravel surfaces. Linear shrinkages are kept as low as 1 per cent. Other tests are conducted to check the constancy of volume of oil mixtures. The swell test devised by Mr. Julian Powers, Materials Engineer of the Arizona Highway Department is used, 50/1000 of an inch swell being the maximum permitted. The surface of the mixture must also be firm and not soft and mushy after being immersed in water for 24 hours. The foregoing tests and an absorption test are the principal ones employed in our laboratory to determine the suitability of gravel for oiling purposes.

Absorption Test

The absorption test is conducted as follows:

An arbitrary assumption is made and it has been closely enough borne out in experience that the completely dried material will absorb within its pores in five hours as much water as it will oil under road conditions.

The test is run in connection with the wash sieve test in which the following sieves are used: 1 inch round, ¾, ½, ¼, Nos. 10, 20, 40, 80, 100 and 200 mesh square. The part of the sand passing the No. 200 mesh sieve is rejected for this test. It is always sticky and interferes with the surface drying operations. The sizes retained on the above sieves are immersed separately in water for five hours and then surface dried. The gain in weight represents the absorption of the material. In practice on the road we determine the lowest point to which the moisture content of the material can be reduced with reasonable work on the part of the contractor. This moisture

content is subtracted from the laboratory absorption factor furnished the engineer to obtain the field absorption factor. The laboratory work connected with this test is very exacting. Skill and judgment on the part of the operator is required to find the exact end point in the drying operation.

We do not depend wholly on the accuracy of this test. The absorption is further checked by the laboratory mix which is subjected to heat for a period of 30 days. A large size sample is supplied from the work. The oversize is crushed and added to the remainder of the sample, and enough of the material is separated by the wash method to produce a 20 lb. test mixture. The following formula is used to figure its oil content:

P=.01A + .02B + .03C + .05D + .06E + .08F +.195G + H.

P=Percentage of oil.

A=Percentage of aggregate larger than No. 10 mesh.

B=Percentage passing No. 10 mesh and retained on No. 20 mesh.

C=Percentage passing No. 20 mesh and retained on No. 40 mesh.

D=Percentage passing No. 40 mesh and retained on No. 80 mesh.

E=Percentage passing No. 80 mesh and retained on No. 100 mesh.

F=Percentage passing No. 100 mesh and retained on No. 200 mesh.

G=Percentage passing No. 200 mesh.

H=Field absorption factor.

The percentage of oil necessary to paint the minus 200 mesh gravel is obtained by experiment and varies between 12 and 26 per cent. The value of 19.5 given above is only an average. This paint factor is always supplied to the engineer.

If you wish a simpler formula, the following will serve for average conditions:

P=.01A + 0.043B + .195C + H.

P=Percentage of oil.

A=Percentage of aggregate larger than No. 10 mesh.

B=Percentage of aggregate smaller than No. 10 mesh and larger than No. 200 mesh.

C=Percentage of aggregate smaller than No. 200 mesh.

H=Field absorption factor.

Remember, if any of you use either of the above formulae, you must seal the surface before winter, and also use an absorption factor. In some cases the absorption factor is zero, but we have oiled material where this value has been as high as 3½ per cent.

The test mix is kept in an oven maintained at 120°F. for a period of 30 days. At the end of this time the mixture is subjected to the action of an auto wheel propelled over the surface of a circular track about 5 feet in diameter. If the mixture fails to compact under this test it will not give satisfactory results on the road. The apparent specific gravity and weight per cubic foot of mixture is checked at this time. Finally, before the project engineer leaves to take charge of the work he examines and criticizes the mixture. Often slight changes are made in the absorption factor as a result of this test.

With information furnished by the above tests the project engineer can intelligently examine the materials on the work and accurately predetermine the amount of oil required. The procedure in the field is as follows:

Graveling contracts usually precede the oiling contracts a short time. However, of late, graveling and oiling have been let in the same contract. In either event the oiling engineer usually takes care of the gravel contract. Accurate wash sieve analysis are taken at 500 foot intervals during the placing of the gravel. The oiling engineer has this information and in addition, before oiling commences he checks the grading of the gravel at 500-foot points, arranged 250 feet distant from the original test points. Duplicate tests are run at several of the original points to enable the engineer to form some idea of the change of grading of the gravel which has occurred under traffic. The sieve analysis and the information furnished the engineer from the Salt Lake laboratory, together with the weight per cubic foot of the gravel enables the engineer to determine the correct end area of the windrow and the proper amount of oil to apply.

Correct sampling is very essential in this pre-determination work. Our engineers have preferred to sample the compacted gravel surface before scarifying commences. Experience has shown this method to be more accurate than sampling from the loose material after scarifying. From the results of these sieve

analysis a table is furnished the inspector, giving the correct amount of oil to apply at different points.

In order to be assured that the proper quantity of gravel is provided to give the required depth of mat, the windrow is checked at 25-foot intervals. This is done by means of a triangular frame. A motor patrol follows the man with the frame and more gravel is added or taken away as required. The original amount scarified is usually slightly less than that required so that a small amount of new material is added. This enables the contractor to clean up any loose gravel.

Where the sampling and testing have been accurately done, the mixtures work out closely to the pre-determined figures.

So far in this paper nothing has been said about the desired grade of sand and gravel necessary to give good results. Utah specifications require the materials to be graded between the following limits:

Passing a 1 inch round opening	100%
Passing a ¼ inch square opening	45-60%
Passing a No. 10 mesh opening	30-50%
Passing a No. 200 mesh opening	3-12%

Mixtures carrying near 60% through a ¼ inch screen are more workable than those having smaller amounts and it is usually possible to produce a smoother riding surface. A reasonably large percentage of sand between ¼ inch and No. 10 mesh is desirable from a stability standpoint. Five to eight per cent of dust passing through a No. 200 mesh sieve gives good results.

The completed gravel surface road should be kept under traffic and intense maintenance before oiling commences. The gravel surface and shoulders should be in as nearly perfect condition as to contour and profile as possible. The gravel is next scarified to the depth and lines established by the engineer. This work is usually done by means of motor patrols, or caterpillars pulling heavy graders with scarifier attachments. The gravel thus loosened often carries a considerable percentage of surface moisture which must be removed before any oil is applied. The moisture content of sedimentary gravels must be reduced below ¾ of one per cent. Materials of igneous origin occurring in Utah are always more absorbent, so a higher percentage of moisture is permitted. For satisfactory results, as much surface moisture is evaporated as possible and the moisture content reduced to 1.5 per cent.

Having reduced the moisture content of the material to the proper point the gravel is placed in a windrow near the center of the roadway. The surface is scarified to such depth as to give the desired quantity of gravel to produce the proper thickness of oil mixture. In Utah the average gravel requires approximately 750 lbs. per linear foot to produce an oil mat three inches in thickness with a width of 20 feet. We use an average of 330 lbs. of oil mulch per square yard to obtain this thickness.

Methods of Mixing

Two methods of mixing are commonly used in the Western States. The oldest and the one most used is commonly referred to as the "blade mix." The second makes use of traveling mixing plants. The procedure of scarifying, drying, and checking of the windrow described above is the same for both methods.

Mixing by Use of Blades on the Grade

Oil Application.—The prepared gravel is spread uniformly over the base, and is then ready for the first application of oil. The engineer from his examination of the gravel determines the correct number of gallons of oil required per linear foot. The oil is distributed in sections and the length of the section is determined from the capacity of the distributor. The section is made short enough to require a little less oil than the tank capacity. The oil application is one of the most difficult and important operations in this type of mix. It is very necessary that each spread begin and end exactly at the section boundary. Any overlap causes rich spots to develop in the completed surface. Usually ½ gallon of oil per square yard is spread at an application.

Much of the trouble encountered in the control of mixtures can be traced to poor oil spreading. Part of the difficulty is caused by the equipment lacking sufficient power to maintain the desired speed over the loose gravel on which it is forced to travel. Oil is usually spread on one-half of the road while traffic uses the other half.

Projects are frequently located as much as 100 miles away from the nearest railroad point. Often as many as 15 tank trucks are required to furnish oil and hauling is continued night and day. From 30 to 40 truck drivers are involved in oil spreading. This creates a difficulty in that inexperienced drivers forced on the contractor by the labor regulations are

not able at all times to maintain a constant speed so that the spread is uniform. Future Utah specifications will outlaw trailer distributors. This will require the contractors to haul the oil to the work in tank trucks and transfer it into approved distributors from which it will be spread on the road surface.

In this event a small number of trained men will operate high class equipment and better results will be obtained.

The distributor is immediately followed by a gang of discs and harrows, which partially mix the material and keep it from picking up too badly under traffic. Some care must be exercised in the harrowing so as not to disturb the sub-base. If the harrows dig too deep and cause grooves in the sub-grade. oil fills in these grooves, making thorough mixing difficult.

After all oil has been applied, the loose mixture of oil and gravel should be placed in the windrow and is then ready for mixing to proceed. In this operation care must be exercised to see that the floor is thoroughly cleaned of all loose material and that no free oil has seeped into the gravel base.

Three variations of blade mixing have been used in Utah as follows:

1. The method making use of motor patrols only.
2. The combination of heavy graders pulled by large caterpillars and motor patrols.
3. The method making use of large graders pulled by caterpillars and discs and harrows.

Mixing With Motor Patrols

In this method the contractors in Utah have used from 4 to 8 modern pneumatic-tired motor patrols. With the windrow of partially mixed oil and gravel near one edge of the roadway the first two patrols cut the material from the edge of the windrow and move it toward the center. The third patrol heels this material over, the heeling operation consisting of pushing the material with the heel or rear part of the blade. It is pushed into the windrow and at the same time lifted up and over. This operation exerts considerable pressure so necessary in coating the large rock with oil. This operation is repeated until the entire windrow is moved.

The mixing space is confined to the width of the oiled roadway. No mixing is permitted on the shoulders. 12-foot blades are a little too long for an 18-ft. roadway, but serve very

well where a 20-foot space is available. In blading the material from one side of the road to the other it is important that no partially mixed oil gravel be left on the floor. Free oil allowed to seep into the sub-base gravel frequently causes rich spots to appear in the completed surface.

Combination of Graders and Patrols

Where this method is employed, the contractor frequently provides three large graders powered with caterpillars and three or four motor patrols. With a partially mixed windrow on one side of the roadway the three heavy graders start at the top of the windrow and slice the material toward the road center. The motor patrols follow and clean up the floor of the grade, placing the material in a windrow near the center.

Another similar operation places the material to the opposite side of the roadway. These operations are repeated until the material becomes thoroughly mixed.

Methods Used in Combination of Large Graders and Discs and Harrows

This method was first used in Utah by Nevada contractors. The mixing equipment consists of two large graders with ten foot blades and pneumatic tires, pulled by caterpillars and two or three gangs of discs and harrows pulled by caterpillars. The system does most of the mixing near the center of the road. With the windrow of oil and gravel near the road center, the first large grader passes over it with a straight blade, merely flatening it. Next, the two or three gangs of discs and harrows pass over it. The second blade then turns the material on the right of the windrow toward the center, picking the material up clean from the grade. This grader man must be very skilled. The above operations follow each other very closely, and by the time the last blade reaches the end of the section, the ones preceding it are turned around ready to start back and the entire operation repeated.

We have found a small amount of material near the center of the roadway that was not moved by the above operation. So the windrow was occasionally split and moved to each side of the road, then back to the center again where the original operations were repeated. This system of mixing requires less skill on the part of the blademen than the other two. The discs and harrows are very effective as mixing machines. With one skilled blademan there is little difficulty keeping the windrow

in uniform shape. Control is comparatively easy and traffic can pass over the windrow with little difficulty, it being wide and flat. All machines move with the same speed, either on the level ground or on hills. This fact makes for less delay at turn points.

Where motor patrols are used, they also move at the same rate of speed and are well adapted to work on soft gravel or sandy floors. They are also easy to turn on soft shoulders and borrow pits. These facts make it easy to keep the windrow in the same shape for its entire length.

One of the disadvantages of the combination system of graders and patrols is the difference in speed of the different units, especially on grades. This causes some delay in making turns. It is very much more difficult to take care of traffic with this system and that making use of motor patrols than the so-called Nevada system.

Mixing by Use of Traveling Plants

The second major method of mixing is by the use of traveling plants. Scarifying, drying and checking of the windrow for size and grading is of the same importance where the machine method of mixing is used as for the blade method previously described. In this case, the windrow is placed near the right edge of the roadway before mixing commences. The base has been checked for conformity to the plans as to cross section and profile.

With the windrow placed in the right half of the roadway, and the left half cleaned of all loose material and the thickened edge properly shaped, a tack coat of MC-1 cutback is applied to the left half of the roadway. From ¼ to ½ gallon per square yard of cutback is used, depending upon the condition of the gravel base. This usually penetrates through the base in a few hours or so to permit traffic to pass over it without any danger of picking up free oil. Mixing commences as soon as the tack coat material has become thoroughly absorbed into the base gravel.

Two types of very similar mixers have worked in Utah during the seasons of 1934 and 1935. Each is provided with loaders which take the material from the windrow and elevate it into a hopper above the mixers, where it is fed into the mixing compartment by means of an apron feeder. The oil is sprayed into the gravel at the end of the feeder before it enters the

mixer, and the oil spray is synchronized with the gravel feeder. Adjustments can be made in the machine to meet radical changes in the grading of the materials. Small changes in gravel feed are made by raising or lowering a gate regulating the height of the gravel on the feeder.

It is very important to regulate the speed of the machine so as to keep the hopper above the feeder nearly full. Indicators on the outside of the hopper keep the operator informed at all times. The proper mixture of oil and gravel goes to the pug mill, where it is completely mixed and passes out the rear end of the machine to a belt conveyor which deposits it on the tack base on the left side of the roadway. One machine has a twin pug mixer and the other a longer, single pug mixer. In each case the speed of mixing is controlled by the slope of the mixer. The machines are powered by two large gasoline motors. The first one operates the loader and propels the machine, while the second, larger one, drives the mixing end.

Some materials are well graded and mix readily, so more speed is required. A material in cold weather probably could be mixed only half as fast as the same material in warm weather. The machine may be mixing a 1-inch mat on one job and a 3-inch mat on another one, which may also effect the speed.

The power of these machines has been severely tested in our state when mixing in cold weather. Before mixing commences the engineer furnishes the machine operator with the percentage of oil desired and the weight per cubic foot of the gravel. Having this information, trained operators have been able to produce the desired oil percentage. It is only necessary for the engineer to know the percentage of oil he wants with this system.

The percentage of oil given by the machine is entirely independent of the size and shape of the windrow and is only altered by the grading of the gravel as the grading changes its weight per cubic foot. With gravels properly prepared as to uniformity of grading, very little change in weight per cubic foot is apparent. After the machine has completed the mixing, and transferred the mixture to the left side of the roadway, the untreated right side of the roadway is cleared of all lose material, and the thickened edge cut out preparatory to tacking with MC-1 cutback.

The oil is added and after being absorbed by the base gravel, the mixture in the windrow is spread. Traffic is allowed on any part of the grade not occupied by the gravel or mixture. Passageways are cut through the loose gravel and mixed windrow so as to allow vehicles to pass from one side of the windrow to the other. Half of the roadway and shoulder usually provides enough room for traffic to move slowly in each direction.

A third type of mixing machine developed on the Pacific coast by Clyde Wood has also been used in Utah. This machine mixes one-half of the material at a time, which requires more work preparing and checking the windrows before mixing begins. The machine is pulled by a 76 caterpillar. A power take-off from the caterpillar drives the mixing mechanism. This machine also is provided with an accurate oil boot and oil meter enabling the engineer to check at all times the amount of oil being applied. The mixing chamber is suspended from above. Hydraulic jacks control the height at each corner, giving very definite control of the pick up.

The machine is pulled into the gravel, which passes through the mixing chamber without being raised many inches from the ground. A revolving worm arrangement provided with mixing hammers thoroughly distributes the oil throughout the gravel. Some mixing with blades is always required behind this machine.

Field control of this machine is more difficult than that of the other two types because the windrow must be accurately sized and control depends on the amount of gravel passing through the machine, there being no independent gravel feeder or proportioning device. The caterpillar works against the governor, which is set for a definite speed. The oil feed is arranged to obtain a desired percentage of oil. The inspector at the machine is provided with a table giving the oil percentages required at each point. He can check the oil meter and the mixture at any time so that changes can be made almost immediately without inconveniencing the contractor. As an example: Under average conditions we use 330 lbs. of mixture per square yard for a 3-inch mat. From this it can be seen that a cubic foot of compacted mixture weight approximately 146 lbs. For a mat 20 feet wide, 3 inches in thickness it requires 77,818 lbs. of mixture per station.

The inspector's table shows the percentage of oil required

to be four. 3,012 lbs. or 372 gallons of oil are required to cover 100 linear ft. of roadway. The inspector has only to check the oil meter at any time to get an approximate check on his mixtures.

Spreading of Mixed Material

When the mixing has all been done with blades, the completely mixed windrow is placed in the center of the roadway. The base is next shaped to provide for the thickened edge preparatory to spreading the mulch. When this method of mixing is employed no tack coat is used. It is considered that the action of the mixing outfits working many times over the base gravel given it ample compaction to support the surface mat. The tack coat and traffic action is used with the machine method of mixing to make sure that the base is sufficiently compacted. With a 5-inch thickened edge there is more settlement in compaction at the edges than near the center. To counteract this condition the thickened part is filled in first with mulch and compacted with the patrol wheels before the windrow is split. The windrow is then divided, half being bladed to each edge of the roadway. It is necessary that the mulch be completely removed from the center to the edge to avoid uneven compaction.

Having the mulch in two windrows at the road edges, it is bladed back and forth across the surface until the desired smoothness is obtained. Only pneumatic tired motor patrols and skilled operators are permitted to make this final spread. A variation in the spreading procedure is made where the machine method in mixing is used. Here the windrow is moved from the left to the right side of the roadway and back to the center where spreading continues as in the case of the blade mixed material.

Except in cold weather, the only blade mixing that follows the machine is that done in spreading by the above method.

Dragging

Immediately after the spreading has been completed by the motor patrols the surface is thoroughly dragged with a drag 22 feet long having 4 cross members thoroughly shod for cutting. When SC-2 or SC-3 oil is used the cross members are made of 2″x10″ timbers. Heavier drags are sometimes required where cutbacks are used as binders. The dragging operation is absolutely required. It sometimes causes a surface to

shed more gravel, but the added smoothness acquired thoroughly justifies its use.

Rolling

When all spreading and dragging operations are completed and before any volume of traffic is permitted on the surface it is rolled with an 8 to 10 ton roller. This operation is used principally to thoroughly imbed any loose gravel into the mixture, which leaves the edges of the surface as smooth as that portion near the center.

Back Patrolling

A small windrow of loose mixture is sometimes left at one side of the road surface. This is patrolled back and forth across the surface for a few days. The finest of the materials is spilled into the low places and adds very much to the smoothness of the finished road. Slow setting mixtures respond readily to this treatment and their completed surfaces are usually very smooth as a result.

Sealing

Sealing of all surfaces is required in Utah. Present specifications provided for the use of MC-3 cutback. We propose using RC-3 cutback for future work. We have found the rapid curing catback holds the cover material better and that less back patrolling is required. The better results are very obvious in late season work.

Cover material consists of material passing a ½-inch square opennig and being retained on an opening ⅛ inch square. All material in the deposit larger than ½ inch is crushed so the mixture consists of a combination of crushed and natural gravel. Hard type material is required for this use. The quantity of cutback used depends on the condition of the surface to be sealed, relatively dry mixtures requiring more than the rich ones.

The quantity applied varies between 2/10 and 3/10 gallons per square yard. Distributors with accurate control of speed and oil application are required. Trailer distributors are not allowed on sealing work. There is usually much side sway to these machines, making accurate lapping very difficult.

The spreading of oil is always started and ended on building paper to avoid any overlap. The stone chips are spread by means of spreader boxes attached to the trucks. From twenty to twenty-five lbs. per square yard of surface are required.

Before rolling, the stone chips are thoroughly dragged by the use of broom drags. An 8 to 10 ton roller is used to imbed the stone chips into the road surface. Back dragging and rolling are continued as long as necessary.

General Cleanup of Roadway

After all oiling operations are completed, shoulders and slopes and borrow pits are trimmed to conform to the plans and specifications.

Comparison of Mixing Method

Blade Mixing Method.—There are some objections to the blade method of mixing which are not found when the machine method is used. From a standpoint of control, blades are very much inferior. The difficulty encountered in spreading oil is very serious, also many difficulties encountered in the mixing. If the base happens to be in any way loose, the windrow is likely to grow so that when mixing is nearly completed, it becomes necessary to add more oil and do extra mixing. Where trouble of this nature is anticipated, the contractors are allowed to start with a small windrow and it is later checked for size.

The practice of dropping off part of the mixture in the early stage of the mixing is dangerous. On stretches of road having sandy shoulders and borrow pits it is next to impossible for traffic to pass over the road while the blades are at work. The Nevada method of mixing is very much superior to the other blade methods in this respect.

Machine Method.—Control of mixtures is very easily accomplished with this method. During 1934 and 1935 contractors mixed nearly 200 miles using this method and we have never asked one of them to do anything with the mulch except to spread it. There has never been a wrinkled or ravelled spot develop in any of this road. It is true with the blade method where we have been favored with very uniform materials, we have mixed as many as 15 miles in a stretch without having to add oil or cut in clean material. Such experiences are not common, however.

The machine method fails to coat all the large gravel with oil especially in the cooler weather.

The pressure exerted in the blade mixing especially by the heeling operation is quite effective in painting the large gravel. The machines thoroughly distribute the oil among the fines even in cool weather, while under the same conditions

with blades, clods of free oil coated with dust are very numerous and it is nearly impossible to eliminate them.

As stated before, the traffic problem is very much simplified with the machine method. Also the mixing machine makes it possble to use cutback as a binder instead of the SC-2 or SC-3 road oil.

If heretofore you have been in the habit of finding out how much oil your materials require at the contractor's expense, you will not like the machine method, as it is necessary for you to have complete laboratory control to insure satisfactory results.

It is difficult to make an exact comparison of costs between the blade mix and portable plant methods due to the fact that no bids have been let which allowed the use of either type of mix. However, the costs must be very close as on one project the contractor was allowed to use a portable plant after receiving the bid for a blade mix. Stationary plant mix work is now costing us at least $1,000 per mile more than the road mix method, using either the traveling machine or blade graders.

The results of the machine method of mixing on the grade have been so successful that it is the only one permitted in Utah at the present time. The blade method may be permitted on some short stretches of secondary road, in which case permission will be given by a special insert in the specifications.

Utah will still continue to build road mix oil roads.

MODERN PRACTICE IN PLANT MIX

By J. N. Roherty, Research Engineer,
North Dakota State Highway Commission

Plant mix of low cost bituminous surfacing is, in my mind, only a logical development. As we worked with and found the shortcomings and difficulties often encountered with road mix we were not satisfied. No type of road surfacing ever developed has received the wide and intensive study that has the low cost bituminous surface. It can truly be said that low cost roads require the highest type of engineering skill. In order for a road to be low in cost the engineer must get maximum value out of all the materials entering into it. The soil in the

subgrade must be properly drained and properly compacted. The stabilizing base course or gravel base course must be properly graded and of sufficient width and depth. Only when the earth grade and base course are properly constructed should we consider the bituminous mat.

When a weak spot develops in a bituminous surfaced road the public almost always says, "The black top has failed." In about nine cases out of ten it isn't the black top that failed. It was the earth grade or the base course that failed and the bituminous mat, having little or no slab strength, went down with it.

I see quite a number of faces here that I have seen at our meetings for the past 6 or 7 years which were called for the purpose of considering specifications for liquid bitumens. I don't think that our efforts have been wasted at all, but I believe that low cost bituminous surfaces would be even more popular today than they were if we had at all meetings talked of all of the essential requirements and not just of the roof.

You can't make an old building, that is about ready to collapse, new, by putting on an asphalt roof; and you can't make a poor road into a good one by simply putting on a bituminous seal. It must be structurally sound throughout.

What we aim at in the bituminous road is a properly graded aggregate cemented together with the strongest binder that we can incorporate. Of course the aggregate and the binder must be low in cost and the construction must be inexpensive too. Local aggregates and liquid bitumens fulfill these requirements.

The viscosity of the bitumen and the fineness of the aggregate, or rather the density of the aggregate, are definitely limited in the road mix process if we are to do the work economically. In North Dakota we are absolutely limited to the dense graded aggregate type containing from 5 to 10 per cent passing the 200-mesh sieve. There is not a rock quarry in the state and our gravel deposits are fine. In order to have 25% of the aggregate retained on a ¼-inch screen it is frequently necessary to reject sand.

This aggregate has from 40 to 50 square feet of surface area per pound and an SC-3 is the heaviest bitumen that can be efficiently mixed in cool weather. Even then it is slow and costly. Our working season is short and sometimes broken

into by rains. I well remember a mile of road mix just outside of Mandan on U. S. 10 that the contractor mauled around for thirty-one days before he had it properly mixed and fairly dry. It wasn't properly dried even then and the next summer we had to tear it up and dry it some more.

North Dakota was the first state, I believe, to limit the moisture content to 1% by weight. We still believe we were right in so doing. Remember, I am speaking chiefly of dense graded aggregates and binder of the SC-3 type which emulsify and lose their binding power quite readily in the presence of colloidal fillers.

On our first plant mix job we made use of a standard paving plant having a batch capacity of only 850 pounds. The modern plants have a capacity of 4,000 pounds per batch and I do not know that this cannot be successfully increased. The use of this old standard paving plant convinced us that we could get a more uniform product, use a heavier oil and lengthen our working season; for this job was laid late in the year and in weather when road mixing would have been almost prohibitive in cost if not impossible to accomplish.

I do not know how heavy, (as measured by viscosity or float tests) a bitumen can be used in plant mix construction now that the mechanical spreader is here. And the higher we find that it can go, the better it will suit me.

A year ago this summer, one of our successful operators turned in a record of producing consistently between 90 and 100 tons of mixed surfacing per hour. The capacity of the dryer is the limiting factor. In order that you may understand fully the conditions on the job when this production was accomplished, I wish to explain that for the past few years it has been abnormally dry in North Dakota and the gravel deposits did not contain the normal amount of moisture. And too, the contractor took advantage of the drying power of the sun by stripping a wide area of the pit. A mile of mat per day containing 2,000 tons is now possible for the contractor can arrange his shifts to run practically 20 hours. We have nearly that many hours of daylight in June and July. Before the present rules limiting hours of labor came into effect we let to contract plant mix surfacing for as low as $1.10 per ton. This was on a job where the average haul ran about three miles. This price of $1.10 per ton complete in place did not include

the cost of the oil. We pay for the oil separately as the amount is apt to vary quite widely. The $1.10 per ton included taking the gravel from the pit, crushing the oversize, rejecting the excess sand, drying, screening, mixing, hauling, spreading and maintaining until satisfactorily compacted. We had other bids that same year where the price was only slightly higher and this additional higher cost could be explained by and directly traced to a longer average haul.

We believe that modern plants have a mighty good capacity although their limits may not yet have been reached. They give us a uniform product, they have solved our moisture problem. They have definitely lengthened our working season. They enable us to use a far stronger bitumen, how much stronger we do not know. All we hanker for now is money enough to lay all we need.

I finally believe that if we build better grades and stronger bases that we are going to find the truly economical thing to do will be to go to the heavier and heavier bitument. Very heavy road oils and soft asphalts thinned down with kerosene can be readily used with modern plants and I believe them to be a distinct advantage over the lighter products.

Plant moves are expensive, and economical plant mix jobs cannot be expected on short projects, but in the present day demand for roads there is seldom a necessity for short projects.

I do not know that all I have said would be equally true for other types of mixes, but I believe it is. When we determine what grading of our available aggregate will give us greatest stability, we want to secure that grading as nearly as we can with economy. The plant mix makes this possible. Moisture is all too frequently a trouble maker. The plant is to a point where it won't cause trouble. The plant definitely permits the use of better bituminous binders and plant mix construction causes less inconvenience to the traveling public. It is in some cases still a little higher in cost than a road mix job might have been, with a lighter oil, but true economy lies not in first cost, but in the quality of the product. I believe that the plant mix jobs under average conditions are the best buy. The plants are improving every year. One of the best suggestions for the plant men is to provide an auxiliary dryer for the filler. Filler is difficult to dry in one big dryer without quite a bit of loss and while it is another unit of equipment, it has demonstrated that it pays.

TREATMENT OF NATIVE SOILS IN PLACE AND SPECIAL METHODS REQUIRED.

Presiding, H. R. MacKenzie, Chief Engineer
Department of Highways, Province of Saskatchewan

BITUMINOUS TREATMENT OF EARTH SURFACES

By F. V. Reagel, Engineer of Materials
Missouri State Highway Department

There are two general types of bituminous treatment of native soils in place, viz., the surface application type with or without cover material and the mixed in place type.

The first type will be discussed only briefly due to the fact that this subject has been treated in detail in a report of a cooperative research performed by the Bureau of Public Roads and the Missouri State Highway Department. This report covers a total of 229 miles of road in 29 sections and was published in Vol 12, No. 2 of "Public Roads."

Following is a summary of the conclusion reached as a result of this investigation:

Road oil of the types included in the study is an efficient material for use in the treatment of earth surfaces, to provide all-weather roads, provided applications are made to suitably prepared surfaces adequately drained, and repeated as needed. Also adequate drainage, both subsurface and surface, is essential to the satisfactory service of oiled earth surfaces. Adequate drainage on flat topography requires greater crown than is ordinarily provided on graded earth sections. It is interesting to note, however, that lack of drainage is about the only condition that seems to be able to prevent a fair return on the investment in a road oiling job. The fact should be kept in mind, in the discussion or illustration of defects, that, in the main, the effects of practically all unfavorable conditions are generally localized and render only relatively small areas of surface inconvenient to traffic. Oiling the surface is, however, a splendid poor drainage detector, practically the only areas failing completely to carry traffic being traceable to lack of drainage. It is sometimes a problem to convince maintenance and construction operators that minor lack of drainage such as small shallow dips and lack of crown, such as will permit the reten-

tion of water puddles on the surface, constitute poor drainage. Slight exaggeration of crown will go far to eliminate trouble from this source.

General profile is not a factor affecting the service of oiled earth surfaces except as variations may influence the efficiency of drainage and the character of the subgrade material.

The type of oil, as regards basic crude source, is not a major factor, all types yielding fairly satisfactory results with all types of soils, other conditions being favorable. Some oils give somewhat better results than others with particular soil types, but all give fairly satisfactory results.

All soil types so far encountered can be efficiently treated with road oil.

The soil type is an effective factor because of the physical characteristics of the various soil layers exposed to the application of oil. The physical characteristics of the subgrade soils affect the final results according to whether the soils require only the water-proofing qualities of the oil or in addition require an increase in their cohesive properties. The condition of the surface with respect to dust, hardness of crust, and moisture content at the time of application of the oil directly reflects the physical characteristics of the soils. The uniformity of penetration is controlled by the uniformity, texture, and density of the several layers of a soil type.

Soils lacking cohesion and inclined to absorb water very readily in quantities sufficient to cause rapid loss of stability (represented by friable silts), may be more effectively treated with oils having ductile and cohesive bases. Soils which possess cohesion in a high degree and which, when in a still or plastic state, do not absorb additional water unless manipulated (represented by clays), do not require treatment with oils having cohesive bases, as water-proofing without binding will insure fairly satisfactory results. Soils which possess properties from each of the groups mentioned above but can not be placed definitely in either one, may give better results if the quantity of oil applied is increased.

The character of the surface immediately prior to the application of the oil is of **major importance**. Surfaces to which oil is to be applied should be fairly free of dust and should have the pores open to receive the oil. Final preparation of the surface for treatment should consist of blading to eliminate all

dust, crust and depressions of the road surface rather than the movement of loosened material to obtain uniform cross-sections. A uniformly smooth surface to insure uniform distribution of traffic over the entire roadway is essential for the proper development of the surface.

If satisfactory surface drainage has been provided, so that water will not stay on the surface and be forced into and through the oil surface by the action of traffic. the next important requisite to the successful oil treatment of earth is the proper condition of the surface as regards moisture content. For a successful oil treatment it is necessary that the oil penetrate and become intimately mixed with all soil particles by the kneading action of traffic. The mere presence of the proper quantity of oil on or near the surface is not sufficient. All particles must be coated or saturated with oil. The condition of the soil must be such that the oil can enter and mix with all the particles, either by direct penetration or by manipulation and kneading under traffic. The presence of the normal moisture content promotes the condition just stated in that the moisture keeps open the pore spaces and facilitates the uniform distribution of the oil. By its gradual recession or elimination, the moisture promotes uniformity and completeness of the contact of the oil with all particles even though the rate of penetration is retarded to some extent. The character of surface prior to oiling, as previously suggested, is in a very large measure dependent upon the moisture content. The presence of dust is due to lack of moisture. Most clays exhibit considerable volume change with variations of moisture content. On drying, excessive shrinkage takes place, resulting in the formation of shrinkage cracks and a hardened crust separated into blocks by the cracks. This condition is referred to as "hard and crusted" under surface condition survey ratings. The crust has become densified and hardened, and the particles which, in a moist condition were separated by films of moisture, are now drawn into more intimate contact through the stresses exerted by capillary pressure as the water is eliminated. The major portion of the area of the surface is too dense and hard to receive the oil and as a result it enters the cracks between the surface blocks to remain in concentrated form or to distribute itself in the more moist and consequently more receptive underlayers. The blocks of hardened surface receive some oil by pene-

tration around their surfaces, but exhibit a dry and barren interior. If the blocks of crust are not too hard, kneading of traffic may tend to remedy the condition by helping to redistribute the oil present in the cracks, but under extreme conditions the blocks remain hard and unreceptive. The impact of traffic often causes the surface-coated but unpenetrated blocks to be displaced, starting the familiar condition of raveling and pot-holing.

Lack of moisture, in the case of soils which have lower volume change with loss of moisture, such as the silts or sandy soils, is not so serious, as the pores vacated by moisture are occupied to a considerable extent by air and are open to the entrance of oil. Dust forms rapidly, however, on this type of soil. If this dust is not penetrated so thoroughly as to bind it to the underlying soil, it will cause serious peeling and raveling, and barren spots, insulated by dust layers against penetration, will later pit and rut or ravel.

Owing to weather and traffic conditions, the surface to be treated can be maintained in the ideal condition for the reception of oil for only a very short period of time, usually not more than twenty-four hours.

Of sections included in these studies, the best results were obtained on those sections which were bladed the same day the oil was applied. Blading at this time cut down to the zone of normal moisture content and the treatment followed before the moisture had receded from the exposed surface.

Weather conditions are a factor to the extent that they may influence the moisture content of the surface, the rate of penetration and the quantity of oil, if loss occurs due to rainfall immediately following application.

Within the ranges observed in our experience, there does not seem to be any significant effect of air temperatures except as they might serve to speed or retard changes in the moisture content of the soil.

Contrary to general expectation, there is no apparent benefit to be gained by raising the temperature of the oil above that required for uniform distribution. Increasing the temperature of the oil only increases the tendency to flow along or from the surface due to decrease in viscosity, and is detrimental rather than beneficial.

A retarded rate of penetration tends to improve the uni-

formity of distribution of the oil, thereby promoting the intimate mixture of oil and soil particles desired. Non-uniform penetration which usually accompanies a rapid rate of penetration fails to produce the results desired.

The presence of untreated earth surfaces adjacent to oiled earth surfaces reduces to a varying extent the effectiveness of the oiled surfaces particularly if the untreated surfaces are manipulated, as the untreated earth and dust tend to adulterate and deaden the treated surface. All surfaces, if possible, should be oiled full width.

A development of considerable importance, although it does not have an important effect upon the efficiency of the oiled earth surfaces as a traffic way, was brought out by observation in connection with these untreated widths in comparison with the treating of full widths. This development was the great efficiency of oil treatments as a means of stopping washing of soils of the noncohesive type such as those derived from silts. In certain areas, the Highway Department was faced with the necessity of purchasing additional widths of right-of-way to obtain earth for replacement of earth shoulders removed by erosion. Oil treatment of shoulders immediately and effectively stopped this erosion, saving many dollars in maintenance cost. In extreme cases such simple treatments enabled the holding of fills subject to overflow, which previously and periodically had been lost. After oil treatment, these fills resisted action by virtue of the thin stabilized layer which prevented the inception of washing and crumbling. This development leads us to include the factor of conservation of material in our future considerations for rating effectiveness of oil treatment.

Non-mutilative traffic, as previously suggested, is highly beneficial to oiled earth surfaces, as such traffic tends to kneed the oil into intimate contact with the soil particles. This intimate association is a primary requisite for successful treatment of earth with oil. There are strong indications that the serviceable life of the treated road is materially shortened if traffic during the first month after application is not sufficient to furnish the desired kneading action to thoroughly incorporate the oil into the surface. Oiled sections, that have been closed to traffic on account of other construction activities at each end, show extensive dusting in one to two months after application, the oil turning a light brown in color and being dead in ap-

pearance, almost entirely devoid of binding properties. The same tendency is almost always exhibited on traffic lanes which, due to excessive roughness, are avoided by traffic early in their life. The traveled lanes will remain in good condition and the balance of the surface will dust and ravel extensively.

Mutilative traffic, such as herds of cattle, lug wheeled tractors, etc., seriously impairs the service rendered where encountered. This traffic, fortunately, is generally localized. During the winter and early spring, the surface is least resistant to mutilation by traffic and any reasonable and practical means of mitigating this effect will justify some expenditure. In some cases, cover material consisting of a thin layer of clean river sand has been applied with beneficial results. An excess, however, must be avoided unless succeeding applications are made to build up an appreciable mat.

Dragging or blading of a good oiled earth surface is generally harmful. When reshaping is necessary, a retreatment should be given to restore the oiled surface.

Maintenance Methods

A road to be reoiled is usually gone over by the Killefer disc prior to the application of oil. This machine consists of four sets of steel discs set at a slight angle to the center-line of the road so that the weight rests on the discs. The discs turn as the machine proceeds, resulting in a row of narrow longitudinal cuts produced by shear. This action does not produce or permit progressive skinning or peeling. The axles on which the discs are mounted can be raised or lowered as may be necessary to make more shallow or deeper cuts in the surface. Those not familiar with this piece of equipment will be interested to find that it furnishes a very efficient method for smoothing out almost any type of bituminous surface.

The Killefer disc is followed immediately by a multiple blade maintainer which mixes the loosened material and moves it to any depression. A motor grader follows this machine and finishes the smoothing or leveling process. Thus with one passage, the humps are removed, the depressions are filled and the entire surface is smoother. The loose material will rebind with the surface if reoiling follows this operation within a reasonable length of time. Most of the fine shavings will, however, be blown or washed away or lashed off the roadway by traffic if

much time elapses between the smoothing operation and the application of the oil.

Surface defects of limited area are, when necessary, maintained by patching. A mixture of earth and the type of oil used in the original oiling are used for filling material. The hole to be filled is cleaned of all loose and foreign material and the patching material is tamped in and given to traffic.

The successful patching of a surface of this kind seems to be largely dependent upon the curing of the patching material prior to use. Mixtures made by hand can be stockpiled for long periods. Another method for obtaining patching material in a cured condition, with a minimum of effort, is by digging a pit to a depth at which soil containing the normal amount of moisture is reached. This pit can be filled with oil and nature does the work. When patching material is desired, it is readily obtained by digging from the pit and is available the year round because it never freezes.

Extensive defects may be successfully patched, if desired, by excavating to a depth of about six inches and filling with a mixture of chat and asphalt cutback with kerosene, following with a light covering of dry earth.

Road oil applications have been generally considered as only temporary maintenance expedients. We believe that this material has not received the serious consideration as a construction material that it merits if handled with a view to obtaining the maximum of service from its use. The addition of large mileages of low cost, farm-to-market roads to highway programs, should introduce a new and increasing field for this type of construction.

As a discussion of the second type of treatment in place, we desire to offer a description of some recent experimental work, now under way in Missouri and which we believe involves something new and of possible interest to organizations making considerable expenditures for base stabilization.

In the early stages of the development of our low cost road program, we advanced through the use of the gravel and crushed stone types, with their attendant dust and loose material hazards, to the use of a mat type. At first, old established bases were available but the urge for dustless surfaces brought considerable pressure to bear and the application of mats soon extended to bases of insufficient support as, for

example, regular unreinforced gravel and crushed stone roads. It seems to be characteristic of these types, particularly in the case of the gravel surface, to reach an equilibrium thickness of about two to two and one-half inches, regardless of the amount of materials added and provided and moderately high intensity of traffic uses the loose surface.

The failures experienced on such insufficient bases forced us to the consideration of base stabilization, while in the meantime we had been improving the types of mat surfacing. The use of calcium chloride gravel stabilization plus higher cost surfacing produced so high a total cost that we have been forced to the conclusion that some steps must be taken to develop a truly low cost type of base plus surface.

An analysis of the situation brings us to the realization that soil or subgrade support is the basis support with which we have to deal. If at the proper moisture content, the soil will support any practical load, which is true in the majority of cases, then the simple stabilization of the moisture content will achieve our purpose to the extent that such stabilization can be made permanent. It is a broad statement, but it follows, that if we can find a practical durable way to stabilize the moisture content of soils in the field, we will need no other type of construction. Failing in this objective, the next step in design is to spread the load over sufficient area to meet the limited supporting power of the soil at the moisture conditions experienced or else change the characteristics of the soil phase by adding friction material. Excluding the latter as belonging to a subject outside the scope of this paper, we find that the spread of bearing, due to the coning effect of superimposed layers, leaves a number of options also beyond the scope of this paper.

Our conception of the difference between base and surface is that bases are simply additional thickness protected against reduction in thickness from traffic action, by means of an additional layer (the surface) designated to resist the abrasive action of traffic. The protecting layers so far devised are by far more expensive than the bases, thickness for thickness.

If we are correct in our assumption that a durably waterproof thickness of soil is of just as much value (aside from resisting the abrasion of traffic) as an equivalent thickness of high type surface (again discounting beam strength) we are

driven to just one conclusion—get busy on the base and drive in the direction of waterproofed bases plus relatively thin renewable cover coats, as a solution to our low cost road problem. We can get at the thin renewable surface to preserve or improve, but it costs to work on the base after the top has been once placed.

This is the line of reasoning on which we are basing our plan of research attack on the low cost road problem.

The problem is a large mileage of earth roads and worn out gravel and crushed stone roads of little thickness, to be improved to give dustless, safe service to present and future traffic at a reasonable annual cost including maintenance expenditures.

Considering only the bituminous angle, can we add sufficient oil to a sufficient thickness to durably waterproof without inducing a plastic condition and thereby losing the inherent stability of the soil? If not, can the plasticity so induced be overcome by the addition of an economical amount of friction material?

The experimental work to which we have previously referred, consists of two methods and we desire to stress the fact that only preliminary indications are available at this time.

1. The Ingles or subterranean method is a method for the deposition of a quantity of liquid bituminous material at the bottom of a scarified layer of earth or earth covered with granular surfacing, followed by compaction to permit the oil to permeate upwards through the mass. This method was first tried in Jackson County on county roads and then, after such applications had shown promising results, ten miles of experimental sections were constructed on our State Highway system.

The method as now developed consists essentially of scarifying the existing roadway to a depth of four or five inches, followed by the introduction of the bituminous material with or without the prior or subsequent application of a small amount of water or soap solution. Following the application, the roadway is kept smooth under traffic and rolled if necessary to obtain the desired compaction.

The equipment for application consists of a heavy frame, supporting hollow curved teeth which project down to the desired depth and through which the bituminous material from an accompanying distributor is forced by means of a pump mounted on the rear.

The bituminous material added has included SC oils, MC oils, MC oils emulsified, and commercial emulsions. The quantities vary from approximately three to seven per cent of oil by weight of the layer treated. These quantities attempt to bracket the optimum quantity, or in other words, to obtain some sections too lean and some too rich, in order to obtain the maximum of information.

It seems to take about two to three weeks for the oil to permete the mass, the final stage of diffusion seeming to follow a rain. The final result hoped for and apparently, from preliminary indications obtained, is a waterproofed layer from four to five inches in thickness. All granular material present in the surface seems to be well absorbed with the exception of a very small quantity of floating material.

To a number of sections varying quantities of aggregate were added prior to scarification in order to test the efficiency of additional friction material in case too great a degree of plasticity was induced.

It is apparent, in our opinion, that the final result is a base and not a surface, but it is hoped that the base obtained, at a cost of approximately twenty-five hundred dollars per mile, will require only a light armor coat as a surface, the resulting combination, if successful, being obtained at about one-half the cost of other types of low cost construction.

2. Since we were somewhat skeptical of the success of this method, we tried a second method in which we scarified the surface, windrowed the material and mixed with the desired percentage of bituminous material by means of a traveling plant (Barber-Green type).

The variations obtained with the first method, including added granular material were approximated under this method but at a considerably increased cost. The advantages hoped for in the second method were greater uniformity, better mixing and better control. Only about six miles of the contemplated ten miles of test sections were completed before winter weather caused a shutdown, but sufficient sections were constructed to give possibilities of an interesting comparison after the effects of traffic and weather during the winter season can be observed. The cost of treatment by this method will probably be about four thousand dollars per mile.

Mention has been made of the use of soap in connection

with this work. This addition is not primarily made in order to produce emulsification, but for the purpose of promoting a beneficial chemical action between the oil and soil surfaces. A brief discussion of this phase of the problem may be of interest.

For the past two years, Dr. Winterkorn, of our staff, has been working on the problem of the chemical stabilization of soils basing his studies on the physicochemical characteristics of the soil surfaces and of various treating media. The following discussion is based on his work.

This work has developed that surface properties rather than the ultimate composition or mechanical character of the particles are important. It is the surfaces and interfaces that determine the plastic properties of a system and its comparative resistance to water. The more finely divided a substance the more surface and the more important the surface properties. For example, a cube of dense material has but 6 sq. cm. of surface whereas a centimeter cube of clay will develop acres of surface. If waterproofed with the same thickness of film the quantities required would be in the same ratio as the surfaces. Fortunately we do not need to coat the finer particles so thickly. Theoretically, a layer one molecule in thickness or about one ten-millionth of a centimeter, would be sufficient to change the surface characteristics, the soil particles being assumed to be about one one-hundred-thousandth of a centimeter in diameter.

In dealing with bituminous material as a chemical treatment, however, we desire to link the film to the soil particle as firmly as possible. One method of doing this is by means of soap. This linking gives greater resistance toward the slaking action of water as well as a greater tensile strength of the system. The benefit can be observed by observing windrows of material with and without the addition of soap, when subjected to heavy rainfall.

Our studies on waterproofing have shown that the affinity of soil surface vary greatly according to the kind and quantity of ions on the surfaces. It has been shown for example, from swelling data that the water affinity for one gram of Putnam soil colloid varies from 5 c. c. for Potassium ions on the surface to 4 c. c. for sodium ions or a difference of several hundred per cent. It is therefore apparent that a change in

surface ions can decrease the affinity for water and so foster and build up the protective effect of bituminous material.

Other facts pertinent, are that the asphalt molecules should be in one dimension one one-hundredth the size of the soil colloids. The soils have a rod or plate structure and evidence is beginning to accumulate that asphalt also has similarly shaped particles.

We have attempted to somewhat briefly indicate that it is possible to markedly change the physico-chemical character of the soil colloids by slight changes of the composition of the substances absorbed on the surface. It is to be expected that a continuation of these studies will reveal ways and means to also change the properties of asphaltic materials in the desired directions. This type of study should be one of the most important new tasks for the chemist connected with road construction.

SAND SURFACES

By Frank S. Gilmore, Highway Engineer

The Asphalt Institute

In the short time allowed for presentation, it will be possible to only touch some of the "high spots" of our subject and hope that by making the paper brief, some point may be brought out which will be of interest and value to those attending this conference.

Sand hills and blow-sands, or dune sands, occur, among other places, along the Arkansas River in Southwestern Kansas and over approximately one-third the area of the State of Nebraska. Since modern methods of oiling sands in Nebraska started prior to Kansas work of like nature, and since Nebraska work of this character has been more extensive than Kansas work, discussions in this paper will be confined to Nebraska except where a confirming Kansas practice might be of interest.

The soil of the sand hills is reported to be not quite so coarse as those beach sands at Daytona Beach, Florida, made famous because of automobile speed records established there. However, unlike beach sands, these blow-sands, or dune sands of Nebraska, and other western states, are not smoothed out and compacted by tide waters. Only when wetted from rains

or melting snow is the stability of these sand mixtures increased because of a moisture film as is the case at certain times along the beaches.

Especially during dry weather periods when natural soil surfaced roads throughout the West are most stable, untreated sand hill roads are likely to offer most difficulty to motor vehicular traffic—at times becoming impassable. A covering of straw, thistles, weeds and other like material has often afforded the only temporary means of making usable, for vehicular traffic, failed portions of roads through sand hill areas.

Admixtures or toppings of silty soils or clays obtained from local deposits, or at times shipped in, has often been resorted to when sufficient funds were available and the road carried enough traffic to justify the expenditure.

By the use of clay a graded sand soil mixture is obtained having stabilities comparable to those obtained in other places with graded soil mixes. However, the clay binder will wash out during wet weather and will blow out during dry weather requiring constant maintenance and periodic replacement of lost materials in order to keep the road in serviceable condition.

When a clay road is surfaced with gravel it is the gravels that grind up and wash or blow away and which require replacement. When a sand hill road is topped with clay it is the clay which is washed and blown away and which must be replaced.

It is quite conceivable that under some conditions the cumulative cost of original clay, plus clay replacements over a period of years, could mount to an abnormal figure. Doubtless, these costs, plus the desire to produce a higher type surface or pavement, making a maximum use of the local sands, prompted the first experiments with liquid asphalts and sand mixtures.

The use of liquid asphalts in the stabilizing of blow-sands in Kansas, Nebraska and other sections of the West, has been successfully carried on for a number of years.

More than fifteen years ago a sand hill road in Finney County, Kansas, was stabilized with road oil. The road was later abandoned, probably as much because of its location as for any other reason. An examination of those portions of the road which are readily accessible indicates that the width of the treated section was narrow and that the road followed

a winding course through the hills over a location not suitable for motor vehicle requirements of even a few years ago.

Recent examination of this early treatment indicates a marked degree of success was obtained and that the sand, from a depth of six to eight inches was thoroughly stabilized. Somewhat prior to 1930, the State Highway Department of Nebraska became interested in the possibilities of developing stable oil-sand mixtures through the sand hill sections of the State. In this early work liquid asphalts of the S-C type were used.

Some projects using special soft base cut-back asphalt, similar in many respects to a material which could be obtained under present M-C specifications, produced results which are, to the present time, satisfactory and which have, in a number of instances, required a minimum amount of maintenance. Because of the experimental characters of these early jobs, results obtained are remarkable. Constant study of the problems involved and of the factors which apparently have an influence upon the results obtained, have brought about a steady improvement in this type of work.

Sand or soil in the sand hill area of Nebraska will practically all pass the No. 50 sieve and usually 95 per cent or more will be retained on the 200-mesh. Around the borders of the sand hill area, materials uniformly graded which will all pass the No. 20 and have a sufficient percentage through the 200-mesh to satisfy stability requirements are often found. These materials when mixed with proper proportion of an asphaltic oil produce very excellent surfaces. Other sands will generally require the addition of either minus 200-mesh or plus 200-mesh material to produce a satisfactory grading. Generally speaking, each project will require some special treatment, and in Nebraska this fact has been recognized and methods of evaluating each project have been quite definitely established since 1932.

In combining liquid asphalts with the sands, and in mixing the sand and selected soils which may have been added, both the road-mix and the traveling plant mix methods have been used. In the earlier work a course oil sand mixture, approximately six inches in thickness was constructed. More recent stabilized oil sand jobs have been of the two course type construction, the bottom four inches being somewhat leaner than the rich, densely graded top two inches or wearing course.

Because of the difficulty encountered in moving vehicle equipment through a dry, loose sand, construction difficulties never encountered in usual road-mix methods of bituminous surface or mat construction have had to be overcome. It has frequently been necessary to pull a distributor and other equipment over the project during construction with crawler or track type tractors.

The scarcity of necessary fine soils or materials has likewise produced problems peculiar to these areas. S-C, M-C and R-C liquid asphalts have been studied and used as have emulsified asphalts and powdered asphalts. Because of the scarcity in some sections of sand or soil having the necessary physical requirements, it has often been necessary to obtain desired results by the selection and use of a particular type of bituminous binder. The reasons for selecting a particular binder can best be illustrated by describing 1935 investigations made prior to the improvement of old oil sand jobs.

During the past season some early oil-sand projects were showing signs of distress. Field investigations developed the fact that when these mats were first constructed the sand subgrade had a moisture content of three or four per cent. After several years of draught the subgrade moisture content had been reduced to less than one per cent with a consequent lack of strength and stability. It was determined that an oil-sand mixture showing a stability of 1000 pounds or less, is not sufficiently stable for these dry sand subgrades but that a stability of 1500 pounds is entirely adequate. Many early oil-sand mixtures as designed had a stability of less than 1000 pounds as determined by the Hubbard-Field method.

On a typical bituminous sand project constructed during the summer of 1931, the natural sandy soil existing in the roadbed, after grading operations were completed, was used as aggregate. Filler material was not added to the sand and oil corresponding to S-C3 was used as binder. Four gallons of oil per square yard was used throughout on this project. The oil was thoroughly mixed with the sand for a depth of six inches. During 1935 failures which occurred on this project were classified and described by the department as follows:

1. A brittle, black surface developed which abraded away easily and resulted in many raveled spots. Sections of the surfacing where the minus 200-mesh was the highest and the oil content the lowest were in the worst condition.

2. A soft mealy appearance developed on some sections. Here the surfacing dusted away very rapidly. Early in 1935 the surfacing rutted and displaced under light loads. The surfacing material on these sections had a very low minus 200 mesh content and a fairly high oil content.

3. The sections where surfacing was very stable and tough remained in good condition except where damaged by livestock. This damage was in the form of small surface abrasions and irregularities. The surfacing material in these sections had a fairly high oil and filler content.

Preliminary Investigations

The types of failures were classified and the entire project was divided into sections according to the condition of the surfacing. Samples were taken to a depth of four inches at intervals of 1000 feet throughout the project. These samples were submitted to the laboratory and the extraction tests, moisture content, and Hubbard-Fields stability tests made. A chart was then prepared showing the stability minus 200 mesh material, and per cent oil. Investigations made to locate filler material within a radius of twenty miles of the project disclosed that filler could not be obtained locally.

Laboratory Designs

A number of mixtures were made up with varying percentages of R-C2 asphaltic oil, M-C2 asphaltic oil, and a special asphalt emulsion (low demulsibility 40-60 penetration asphalt, mixing emulsion).

The results of the stability, toughness, and density tests made on these mixtures showed that it would be nececsary to use three types of asphaltic material on the project.

Where the stability of the bituminous sand was less than 1000 pounds, the percentage of minus 200 mesh less than ten and the bitumen content more than five per cent, it was necessary to use the Special Asphalt Emulsion. The 40-60 penetration asphalt fluxed with the road oil and increased the stability of the mixes more than 50 per cent when the total bitumen consisted of a ratio of two parts of original oil to one part of 50 penetration asphalt. A higher ratio of asphalt to oil increased the stability still more.

Where the stability was between 800 and 1200, the percentage of minus 200 mesh material between 10 and 15 per

cent and the bitumen content less than five per cent, it was necessary to use R-C2 asphaltic oil to provide satisfactory stability.

Where the stability of the bituminous sand was over 1200 and the percentage of minus 200 mesh, 15 or more, and the bitumen content between four and six per cent, it was necessary to use M-C2 asphaltic oil to provide satisfactory stability without excessive balling during mixing by road-mix methods.

Because of the importance to the State of stabilizing soils, especially throughout the sand hill area, and because of the further desire on the part of the State Highway Department to get the highest possible return from their investment in an extensive system and increasing mileage of low cost type bituminous surfaced highways, many factors which might effect results and influence the use and design of bituminous types have been studied. From these investigations the Nebraska men have arrived at a number of interesting findings or conclusions. Many of these are of interest and importance outside of the State. Several are given as follows:

1. The stability of the oiled soil-sand mixtures depends upon the soil-sand gradation and upon the type and percentage of liquid asphalt binders used in the mix. The type and percentage of binder required is dependent upon the soil-sand gradation.

2. It was found that for a given aggregate and bituminous material, stability would increase with increase in bitumen content, up to a certain point and then fall off. This is in accordance with results obtained by other investigators.

3. It was found that with a given aggregate and percentage of bituminous materials that stability increased gradually as the penetration of the asphalt decreased down to about 150—as penetration decreased beneath 150, stability of the resulting mix increased rapidly.

4. With a given sand and asphalt binder, the stability of the mix will increase with an increase in minus 200-mesh material up to a certain point. Addition of material passing the 200 mesh changes, and up to a certain point, improves the aggregate grading.

5. With a given aggregate and liquid asphalt, it has been definitely determined that different mineral powders or fillers greatly affect the stability of the resulting mix. This fact has

been recognized in the field and in laboratory investigations many times before, but it is thought that the Nebraska men are among the first, if not the first, to **establish and assign a definite value** to these fine materials or so-called fillers, indicating their effectiveness in stiffening the asphalt and increasing the stability of the mixes in which liquid asphalts were used in low cost types of highway construction, and in the field of sand stabilization. It is felt that this phase of their work should be described at some length.

In order to describe the methods employed in determining the thickening effect of fillers on liquid asphalt, we must briefly review the Nebraska way of proportioning bituminous binder and aggregate or soil-sand mixtures.

For several years, Nebraska, like other western states, has used a formula for determining the bituminous content required in various gradations of materials. This formula, commonly referred to as the New Mexico Formula, is as follows:

P=.02a + .07b + 15c + .20d

P=Per cent of oil required in the mix

a=Per cent of aggregate retained on the 48-mesh sieve

b=Per cent of material passing the 48-mesh sieve and retained on the 100-mesh sieve.

c=Per cent of material passing the 100-mesh sieve and retained on the 200-mesh sieve.

d=Per cent of material passing the 200-mesh sieve.

This formula does not recognize the difference in the material passing the 200-mesh sieve.

Two years ago the Nebraska Department completed some research work from which a method was developed for determining the stiffening effect of the material passing the 200 mesh sieve when mixed with asphaltic oil. The numerical figure representing this effect has been termed the "S" factor. This factor is applied to the oil content formula by substituting the factor for the multiplier of **d** which, in the original New Mexico formula, was 0.20.

The method used in determining the "S" factor is as follows: A number of mixtures of liquid asphalt and the material passing the 200 mesh sieve are made up in the ratio of ½ to 1.0, 1.0 to 1, 1.5 to 1, and 2.0 to 1, etc. Float tests are then run on these mixtures using 18° F. as the cold bath tem-

peratures and 100° F. as the hot bath temperature. The float time of each of the mixtures is then determined. These values are then plotted on cross-section paper using float time as the ordinate and mineral asphalt ratios as the abscissae. Additional tests or proportions may be necessary to establish a curve. The point on the curve at which a tangent to the curve is approximately vertical is then found. This will be a float time of about 1000 seconds for most mineral powders and the investigators have arbitrarily established the 1000 second float time as the point of comparison with the same point on other curves.

See results as plotted on rectangular coordinate paper, Figure 1, page 100.

It has been found through field experience that for Loess soil material an "S" factor of 0.15 is suitable.

The "S" factor of other fillers is then found by a direct ratio after the float tests are made. The comparison of fillers on this basis has been found fairly satisfactory and excessive and deficient oil contents in the bituminous mats and bituminous sand mixes have been avoided by using the "S" factor in the oil content formula.

Among conclusions from laboratory experiments given by the department are that:

1. The "S" factor evaluates the stabilizing effect of the material passing the No. 200 mesh sieve due to both fineness and surface texture.

2. The degree of success obtained in the use of the oil content formula with the "S" factor when many different types of mineral dusts or fillers are used, as in Nebraska, recommends the continued use of the factor and formula.

For instance, through field correlation of the action of fillers in various mixes, it has been found that a filler having an "S" factor of over 0.3 is to sensitive for successful use. One particular example of this was on a project where Grand Island lime dust was used. The "S" factor of the lime dust was 0.40. A variation of three per cent filler or from seven per cent to ten per cent passing the 200 mesh sieve would require a difference in oil content of 1.2 per cent. In road-mix methods it is often difficult to control closely the filler content and so wet and dry spots may develop immediately after laying the

bituminous mat or bituminous sand mix, although the oil content is absolutely uniform.

A further study of the "filler or S factor" suggests other very practical applications, and in commenting further on this "S" factor of Nebraska, it can be safely said that the results of their experiments have explained results obtained in Kansas investigations reported by Allan and Gibson at the 1934 annual Highway Research Board meeting. In the Kansas investigations it was shown that by changing the type of filler in a given bituminous mix, changes in the stability of the resulting mix occurred, higher stability being obtained when limestone fillers were used than when Loess and Chatt sludges were used.

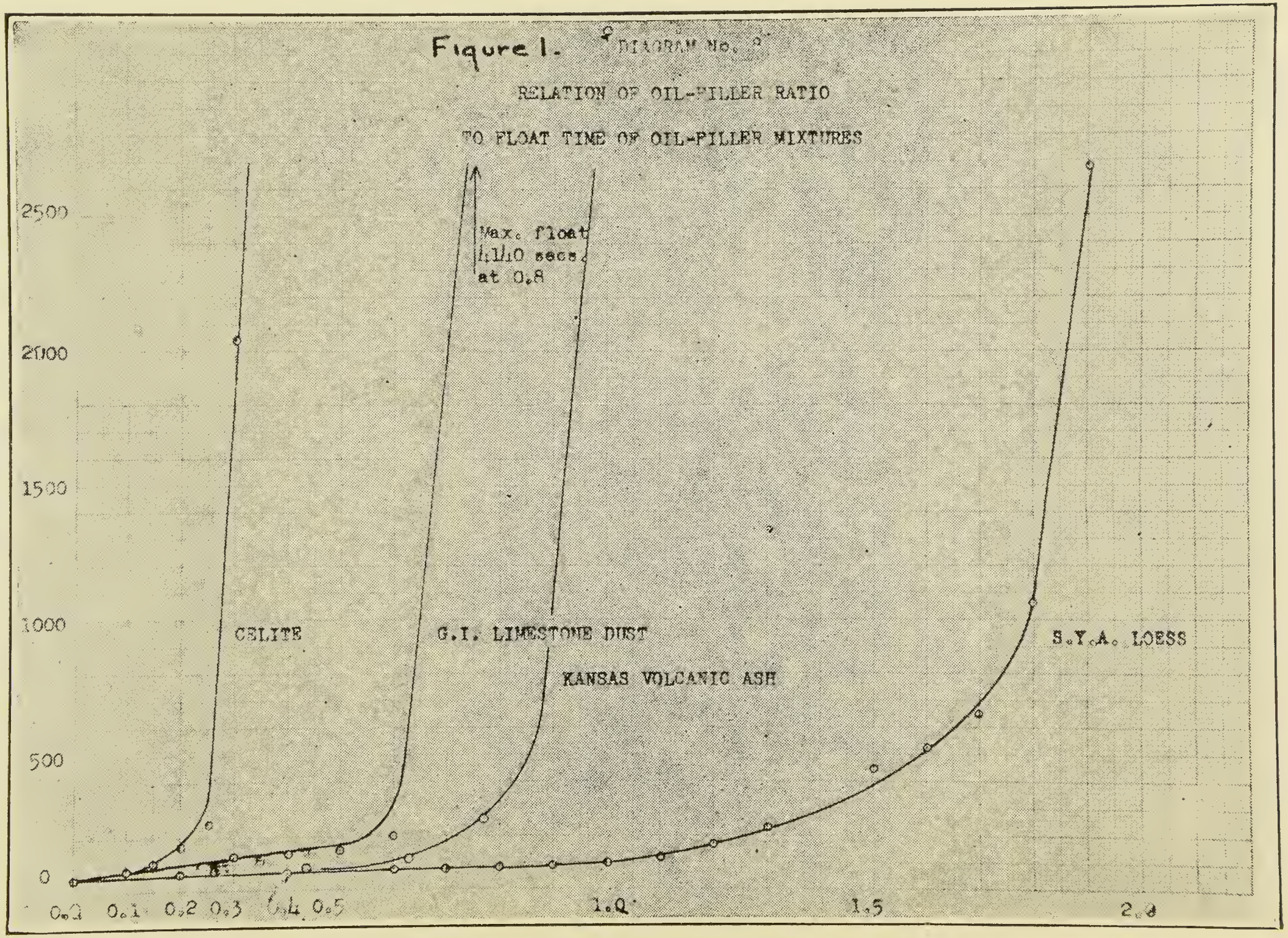
In Nebraska bituminous highway work, the State Testing Engineer and his department, take an important part. The splendid results obtained in Nebraska are a direct result of cooperation within the Highway Department and between the Department and the U. S. Bureau of Public Roads.

To Professor Duff, State Testing Engineer, to his assistant, Mr. Bollen, as well as to other engineers in the State Highway Department, we are indebted for assistance and for information on Nebraska work, making the preparation of this paper possible.

Figure 1. DIAGRAM No. 8

RELATION OF OIL-FILLER RATIO

TO FLOAT TIME OF OIL-FILLER MIXTURES



FLOAT TIME OF OIL-FILLER MIXTURE
In Seconds

PARTS OF FILLER TO ONE PART OF OIL
(By Weight)

SCORIA SURFACES

By L. D. Conkling, Professor of Civil Engineering,
Montana State College

Before presenting the information I have obtained on the use of "Scoria" with a bituminous binder as a road surfacing material, I believe it would be of great interest to those not familiar with Southeastern Montana, for me to give a brief outline of the general conditions existing in this section of our state.

Climate—The climate is semiarid, but there is sufficient moisture during most years to make the raising of crops by dry-farming methods fairly successful on the more favorable soils. Total failures are experienced in some years, and good results in other years, the controlling factors being the amount and distribution of the rainfall. The average annual precipitation is about 14 inches, 70 per cent of which falls in the period from April to September, the remainder largely as snowfall during the winter. The average figures, however, fail to depict the true conditions, because of the annual variations from the average. The precipitation is greater on the highlands of the interstream areas than in the valleys.

Warm days and cool nights are characteristic of the summers; the winters are cold. Temperatures as low as 40 degrees below zero are not unusual, but are of short duration. The range in temperature in a year is commonly as much as 125 degrees. Temperatures below freezing occur in the fall on the average as early as the middle of September and in the spring as late as the last week in May.

Vegetation—The area, served by the experimental road, supports a fair growth of native grasses, and the highlands carry a thin to fairly dense stand of western yellow pines. The pines are particularly partial to areas underlain by clinker (rocks that have been baked by the burning of underlying coal beds), the pines grow chiefly along the edges of the plateaus where the clinker beds crop out. The timber is too small to supply saw logs.

Surface Features—Eastern Montana is part of an extensive plateau, considered in more detail, the surface consists of of a series of great benches or steps, the highest of which form the flat-topped but narrow divides between the major streams

and constitute the remaining remnants of a once more widely extended plateau surface, and the succeeding steps in turn are the remaining parts of large upland plains at lower levels. This steplike series of upland plains results from the regular processes of erosion operating on flat-lying strata of sharply varying degrees of resistance. A hard bed or series of hard beds resists erosion much longer than the intervening soft, non-resistant beds and remains to floor a plain like surface from which the overlying soft beds are stripped. As thick coal beds that occur in the stratigraphic succession are uncovered by erosion they burn along the outcrops and for considerable distances back from the crop lines, and the great heat produced in the burning bakes the beds overlying the coal to a very resistant slag or procellanite clinker. This clinker is known locally as "Scoria." The clinker beds are in many places more than 100 feet thick and commonly are 20 to 40 feet thick. A large part of the clinker or "Scoria" was formed from sandstone grading into greenish-gray and light tan sandy shale and clay shale.

The following is quoted from "Geological Survey Bulletin 831—1931-32.

"Porcellanite or Clinker—Enormous supplies of road-surfacing material are available in the thick layers of clinker formed by the burning of thick coal beds. This material where properly applied forms an excellent road-bed, and it appears probable that within only a few years the main roads in this entire region will be surfaced with "Scoria" as the clinker is called locally. No binder is added to the clinker, as there is sufficient fine material present to serve the purpose for road surfacing."

In this general section, Southeastern Montana, Western North and South Dakota, and Northeastern Wyoming, there are few natural gravel deposits which are available for road surfacing material. The construction of our present types of roads in this section raises a rather serious question, i. e., the securing of a suitable surfacing material.

Scoria has been used with good results as a substitute for gravel in the construction of a low type all-weather road. In this semi-arid region, the dust problem on the low type all-weather road is very serious. Scoria roads are generally far more dusty under traffic than the ordinary gravel type.

The Montana Highway Department, as well as several different state government and private departments, has made a study of "Scoria" as a road surfacing material. As a result of this study, a section of road was built this season by the Montana Highway Department between Miles City and Baker, Montana, using scoria surfacing with bituminous treatment of two types.

An inspection trip over this section of road was made the second week in October. The following are the results of this inspection trip; detailed information furnished by Mr. D. L. Cheney, Assistant Bituminous Engineer, Montana Highway Department; and investigations made by the Highway Department, and other departments interested in this particular type of construction.

Scoria is usually found in solid stratified form, the out-croppings being near or above the general ground surface. Two quarries from which most of the material for this project was obtained were visited and samples of the material secured. This material upon being removed from the out-crop and broken up presents an appearance somewhat similar to clay brick not well burned. There was evidence that some of the material had been heated sufficiently to produce some small quantities of obsidian; there were also some hard lime-coated nodules.

Approximately 80% of the material is a porous burnt clay, brittle, with a high absorption factor, a low specific gravity, low abrasion factor and low crushing and shearing strength.

The scoria showed an absorption of 8% or more. This absorption produced some evidence of swelling and a noticeable softening of the material. The Highway Department made tests using SC-2 and SC-3 road oils. The scoria absorbed these two road oils nearly as rapidly as it did the water. The scoria was found to have a pronounced afinity for water. When a sample of the oil coated scoria was immersed in water the oil film was readily displaced.

Due to the difference in capillary action of the materials, some being very much softer and showing a higher absorption factor, it was difficult to obtain a uniform mix without a complete saturation in the asphaltic material for some period of time. This fact made it apparent that regardless of the amount of asphaltic material used in the original mixture it would be impossible to determine closely enough the absorption factor or

to allow sufficient time between the application of the asphaltic material and the spreading of the mat upon the roadway to saturate the material to a point where there would be no further absorption.

This progressive absorption, after the oil mat had been placed, presented a very high cost maintenance problem. It was therefore decided to eliminate the SC road oils from further consideration due to the high oil factor required, which, of course, greatly increased the cost, and also due to the uncertainty of future stability, service and maintenance cost.

As it had been found, therefore, that it was impractical to oil the scoria with a light oil with high penetrating qualities, it became necessary to find a grade and type of oil which would penetrate far enough into the scoria particles to form a bond and a heavy coating, and fill the voids without permitting complete or continued absorption. Experiments were then made with cutbacks and the possibility of their use in bituminous surfaces with scoria aggregate under two different construction types: 1st—The penetration of bituminous surface method; 2nd—Road mix method.

Bituminous Surface Method

To determine the type and grade of cutback to be used in construction by the bituminous surface method, mats of scoria were constructed in shallow boxes. The scoria was compacted with the aid of moisture to approach as nearly as possible a well compacted road surface from which all loose material had been swept. On these surfaces various primers were tried, finally finding that the RC-2 naptha cutback made the most suitable material for this purpose. Approximately ¼ to ½ inch penetration was secured and this material was applied in quantities of approximately .5 gallon per square yard.

MC-1 and MC-2 kerosene cutbacks were tried, but it was found that they would penetrate too rapidly and did not completely seal the surface, as after applying either of them another application of the same grade would penetrate below that of the first application.

It was found that it would be necessary to allow the RC-2 naphtha cutback asphalt to set for at least 48 hours before applying the second application of oil for the mat section. If this period of time for the partial curing of the RC-2 was not observed the second application of asphaltic material would

follow the RC-2 naphtha cutback into the base and would be ineffective so far as holding cover material was concerned.

After it had been decided that RC-2 naphtha cutback made the best primer, additional scoria mats were prepared as before and primed with RC-2 naphtha cutback and were allowed to stand 48 hours before being given further treatment. Experiments were then made to determine the grade and type of cutback to be used for the second application. It was found that MC-3 kerosene cutback asphalt was most suitable for this application as it did not penetrate the primed subgrade to any appreciable extent and approximately .5 gallon per square yard would bind enough cover material to give an additional depth of approximately ¼ to ½ inch. This depth together with ¼ and ½ inch penetration which had been secured by priming the subgrade with MC-2 kerosene cutback asphalt gave an oil mat of approximately ½ to ¾ inches in thickness.

After the grades and types of asphaltic material had been definitely determined, it was found desirable to make three applications of asphaltic material rather than two applications, using the first application as a primer with approximately .5 gallon per square yard to prime the subgrade and secure the greatest amount of penetration possible, allowing sufficient time for this primer to cure and then applying a second application of the MC-2 kerosene cutback asphalt upon the primed subgrade, followed immediately by a cover coat of crushed scoria. After this asphaltic material had been cured, which required from two to five days, all dust and cover material which had not become incorporated in the oil mat, should be swept to one side of the roadway and the third or final application, using MC-3 asphaltic material, applied at the rate of .5 gallon per square yard, this to be followed by the cover coat of crushed scoria. A total of 1.5 gallons per square yard of asphaltic material had then been applied and an oil mat of approximately ¾ to 1¼ inches was obtained.

A section of the project near Miles City was constructed by the bituminous surface treatment method based on these experiments. However, during construction it was found necessary to make a few changes in the original plan as outlined by the experiments. As the scoria which was used in the surfacing had been in place on the roadway for approximately two years, the grading of the aggregate had been considerably

altered due to moisture slaking and to crushing and pulverizing under traffic and there was an excess throughout the project of material passing all sieves below ten mesh.

On some sections of the penetration it was necessary to scarify the base in order to obtain sufficient cover material. On these sections where the compacted crust was broken leaving an open surface which was not too loose to be swept fairly clean of dust, the RC-2 naphtha cutback penetrated quite satisfactorily. But on those sections where it was not necessary to scarify the existing surface to secure cover material and it was well bonded and compacted, it was not possible to secure the required amount of penetration with the RC-2 naphtha cutback asphalt. In most instances this asphaltic material would not penetrate to any noticeable extent, and it was found necessary to change the grade of primer. Both MC-1 and MC-2 kerosone cutback were then tried. The MC-1 kerosene cutback pentrated quite readily, and applied at the rate of .4 gallon per square yard penetrated from ½ to ¾ inch. However, it was found that after allowing sufficient time for curing, the scoria had absorbed the asphaltic material to such an extent as to leave the primed surface very dry and with very little or no stability. The MC-2 kerosene cutback, while it did not penetrate as rapidly or to as great a depth, gave a more evenly primed, well bonded surface.

The specifications for the bituminous treated surface provided for .5 gallon of asphaltic material in each of three applications. It was necessary to reduce this amount, however, to approximately .4 gallons per square yard as the heavier application had quite a tendency to pool, if the road section was not absolutely true, and would give a non-uniform distribution. Also where the road section was true with the proper crown, the heavier application would flow toward the shoulders and in some instances out beyond the required mat limits. An application of .4 gallon per square yard would not pool or flow and gave a very uniform distribution and this amount was used in each of the three applications.

Neither the RC-2 naphtha cutback nor the MC-2 kerosene cutback would penetrate the base and cure rapidly enough in the specified length of time, two to four days, to permit sweeping or to permit the passage of traffic, so it was found necessary to cover each application of the asphaltic material.

This change, however, did not greatly affect the original construction design as the MC-2 kerosene cutback penetrated the base deep enough to give a good bond with the cover material and the cover material eliminated the possibility of the second application of MC-2 kerosene cutback following the first into the base. The thickness of mat obtained was approximately ½ to ¾ inch in the first two applications.

The third or final application was made throughout the project using MC-3 kerosene cutback asphalt. Satisfactory results were obtained with but one addition or change in the original plan. This asphaltic material did not coat the stone in the cover material as readily as desired, probably due both to the dust in the cover and the curing action of the oil, and it was necessary to resort to rolling immediately following the application of this final coat of cover material. A six-ton, three-wheel roller was used and very satisfactory results were obtained.

After the mat had been in place from three to five days all loose cover material was again bladed uniformly across the oiled section and again rolled. This resulted in a large part of the clean stone, as most of the dust had been eliminated by traffic, being forced into the upper section of the mat where it was firmly bonded, leaving a very durable stone-studded wearing surface.

Road Mix Method

The scoria surfacing which was used in the mix on this section had also been in place approximately two years, and, as has been stated before, carried a rather high percentage of material passing the ten-mesh screen. Two types and grades of cutback asphalt were used in the mix—RC-2 naphtha cutback asphalt and MC-3 kerosene cutback asphalt.

Sufficient scoria material was windrowed to obtain after mixing a 1½″ oil mat, 20 feet in width. The oil application and preliminary mixing was done with a Woods type road mix machine. After this machine had passed through the windrow and the oil had been applied, the windrow was bladed from three to five times across the roadway to permit aeration and to incorporate and coat any loose particles which might have been left on the floor of the mat section. It was practically impossible to form a mixing floor due to the loosening of the scoria base under the mixing machines, and it was found

necessary to take a small portion of the mixed material from the windrow and spread it evenly across the section just behind the mixing machine to form a mixing table and to eliminate the incorporation of additional material from the base. This material under traffic and the blade mixing machine was forced down into the base to quite an extent, filling the voids and stabilizing the loose material and insured the forming of a bond between the base and completed oil mat.

The mix secured with both grades of asphaltic material seemed fairly satisfactory, although the mat has been in place only a short time and it is far too early to make any definite predictions. Due to the nature and excessive quantity of fines, the RC-2 proved to be slightly more workable and easier to mix than the MC-3, but the volatile material in the RC-2 seemed to penetrate and soften the aggregate to a greater extent than was evident with the MC-3. This work was done, however, rather late in the season and as the curing continues, observance of the behavior of these sections during the hotter summer months may prove that there will be further penetration. Should there be, we do not believe that the kerosene volatiles will have the same cutting or softening action as the naphtha material.

Particles of same type and size of the scoria, immersed for a period of time in the two liquids under the same conditions, showed a penetration by the RC-2 of approximately ¼ inch and the entire depth of the material which had been penetrated could be easily scraped off with the finger nail while the particle immersed in the MC-3 showed practically no more penetration than that required to give the necessary bond and a uniform heavy coating of the aggregate. This fact probably accounted in a large part for the difference in the amount of asphaltic material used in each type of mix as the RC-2 mix required approximately 22,000 gallons per mile or an oil content by weight of approximately 13.06%, while the MC-3 mix required approximately 19,000 gallons per mile or an oil content by weight of approximately 10.84%.

While this oil content in per cent by weight seems exceptionally high, it is required in the greater part by three definite factors, first an excess of material passing all sieves below the ten-mesh, and second, the low specific gravity and weight per cubic foot of this material as compared to gravel.

Our average gravel deposits after crushing show an approximate loose weight of 110 pounds per cubic foot as compared to an average loose weight per cubic foot of 63 pounds for scoria. Third: the high capillary attraction for asphaltic material which ranges from 10% to 20% in the baked clay scoria. The aggregate used for surfacing on these projects consisted of approximately 90% to 95% of this material.

Neither of the mats showed a very high susceptibility to water except in instances where the scoria rock in the surface of the mat had been crushed by rolling or by traffic, destroying the oil coating and exposing the broken scoria surface. However, following the laydown and rolling of the mat a seal coat of RC-2 without cover material was applied at the rate of approximately .25 gallons per square yard. This application penetrated to quite an extent, coating any of the particles in the surface of the mat which might have been broken or crushed, and effected a heavy uniform waterproof seal. Future inspections of these sections will probably develop the fact that frequent resealing will be necessary to eliminate, as far as possible, the entrance of any moisture into the oil mat.

No tests have been made to date showing tensile strength, resistance to wear or other general characteristics of these oiled mats in place, and it is too early to predict any definite or probable results. We believe that it may be possible with careful selection of bituminous material, a careful study of the characteristics of the scoria aggregate to be used, and the exercising of the proper care in handling the material in the field, to develop a bituminous treated oil mat of scoria aggregate that will prove fairly satisfactory without too great a financial outlay.

DEVELOPMENT OF THE ASPHALT INDUSTRY IN MONTANA

By W. W. Gail,

Representing Yale Oil Corporation, Billings;
Home Oil and Refining Co., Great Falls;
Independent Refining Co., Billings.

Mr. Chairman, and Gentlemen of the Conference:

Introductory as occasion calls for.

You have all heard of the colored minister who, when asked how he built up a sermon, replied: "Oh, dat's easy. Fust ah tells 'em what ah'se gwine to tell em; den ah tells 'em; an' den ah tells 'em what ah done tole 'em."

When I first began to assemble the material for this talk—which is the proper word for it in contrast to the technical treatises which you have heard, from men who have intimate, first-hand knowledge of their subjects—I feared I should not have enough for the 30 minutes assigned me. I soon discovered that the difficulty would more likely be to cover the subject with reasonable thoroughness within that time. So I shall not be able to follow the minister's system and shall attempt merely to tell you a few facts, with most of which I imagine you are already familiar.

The history of the asphalt industry in Montana is to all intents and purposes synonymous with the history of the three largest independent refineries in the state from which come practically all the state's output of road oils and asphalts, namely, in the order of their establishment, the Yale Oil Corporation, whose plant originally located at Miles City, is now at Billings; the Home Oil Cimpany of Great Falls, and the Independent Refining Co., of Billings, whose plant is at Laurel.

To the men at the head of these organizations belongs the lion's share of the credit for the notable progress which the industry has made. I refer to Mr. L. B. Hancock, president of the Yale; Mr. W. E. Rice, president of the Home and Independent companies; Mr. Phil N. Fortin, vice-president and general manager of the Yale; Mr. H. O. Batzer, vice-president and general manager of the Home, and Mr. Don E. Hageman, vice-president and general manager of the Independent. Every

one of these men knows the industry from A to Izzard, and any one of them is far better qualified than I to discuss the subject. However, since to paraphrase the famous words of Calvin Coolidge, "they do not choose to speak," and have delegated the task to me—you may at least be assured that while I have slight first-hand knowledge of the subject, yet I have been supplied from original sources with all they know—at least all they consider pertinent to the subject and the occasion—and thus I am relieved of all responsibility as to the accuracy of my statements.

For the information and statistics relating to the operation of the refineries, I am indebted to officials of the plants; and particularly, as far as figures relating to the road oil and asphalt branch are concerned, to Mr. Cary Myhre, who is in charge of road oil and asphalt sales for the Home Oil Company and the Independent Refining Co., and to Mr. C. E. Cox, who is connected in the same capacity with the Yale Oil Corporation.

The Industry's Historical Background

The artist in painting a picture pays as much attention to his background as to his subject, for the former gives contrast and perspective. The same thing is, or at least should be, true as regards the painting of a word picture; and on that theory a brief resume' of the historical background of the asphalt industry of Montana as it exists today may not be out of order.

This takes us back to November 6, 1919, just sixteen years and seven days ago, when the discovery well in Devil's Basin was brought in. Three years prior to that date, oil had been discovered on this side of the Montana-Wyoming state line in Elk Basin, but most people, entertaining the old idea, as many do yet, that oil deposits and political boundary lines have some connection, figured that nature had been careless and slopped a little Wyoming oil over onto the Montana side, and Montana got no credit for it.

You all know the story of development since then—Cat Creek, Soap Creek, Kevin,Sunburst, Lake Basin, Bennatyne, Pondera, Border, Dry Creek and finally Cut Bank, in area at least the largest Montana field to date and one of the largest in the country. A regrettable phase, from the angle of the asphalt industry, is that so few of these fields produce a type of oil adapted to its special requirements. However, there is still hope for the future in this respect, as with an estimated

area of petroleum bearing rocks amounting to 70,000 square miles—exceeded by only one other state—it is a trite to say that our petroleum resources are as yet in the infancy of development.

About eight years ago, I was asked to make a talk at an international oil convention at Calgary, on the subject "What I Don't Know About Oil" and, as you may imagine, that assured me plenty of material. A couple of years later I was asked to talk before the Billings Commercial Club on the subject of Montana's oil industry, and under the circumstances was forced to find out something about it. Some of the figures which I dug up and correlated at that time may be of interest and bring us up to the immediate foreground of our subject:

In 1917, two years prior to discovery of oil in Montana, the state's revenue from the oil industry totaled $400. Four years later, in 1921, the total was $46,939.48. In 1927, it was $624,810.87, or more than thirteen times the total for 1921. In 1930, the total sum received by the State of Montana and its subdivisions in direct and indirect taxes from the oil industry, including refining as well as producing, was $814,722.24, or approximately 30% of the state's general fund.

I do not have the figures for the current year relating to the production end, but unquestionably the total is as large as in 1930, if not larger. At any rate, the figures for the refining end—with which we are at the moment concerned, complete a suggestive picture.

Development of the Oil Refining Industry in Montana

The actual beginning of the oil refining industry in Montana, which followed close on the heels of the first oil discoveries, is, I imagine, shrouded in the mists of antiquity, even though it dates back hardly more than fifteen years.

Possibly not the very first, but at least one of the first forerunners of the huge modern refineries of today, was a small topping plant in the Cat Creek field to which, I recall, the first oil from a new well was carried in buckets and within twenty minutes from the time the well came in the operator drove away using the product as fuel in the tank of his Model T. Of course, converting that oil into motor fuel was a simple chore, as the gasoline content was so high that the state chemist, to whom samples from the field had been sent for analysis, thought that

somebody was putting one over on him, and was not satisfied until he had gone to the field and obtained samples in person.

More ambitious plants followed, but for a time the story was largely one of struggle and eventual failure, due in considerable measure, no doubt, to the fact that there was no market for anything but gasoline. However, independent refineries were operating successfully in Montana prior to development of a market for road oils and asphalts and other petroleum products, and, as you all know, gasoline production steadily increased.

As to the exact date of the actual beginning of the asphalt industry in Montana, I am not informed, but the records show that the first purchase of road oil by the State of Montana from a Montana refinery took place in July, 1928. Prior to that time all the road oil used by the state had been imported from Wyoming and California. The purchase referred to, made from a plant no longer operating, amounted to less than 10,000 gallons, which represented about 3.8% of the state's total purchases of 256,360 gallons for the year.

The following year—for what reason I do not know, not a single barrel of the total state purchases, amounting to 652,593.72 gallons, came from a Montana refinery. And never since then, I observe, have fractional gallons been noted in the figures for state purchases of asphaltic road materials and one wonders what became of the hidden three quarts.

The real beginning of the industry in the state may probably be said to have come in 1929 when the manufacture of road oil and asphalt on a fairly large scale was begun by the Yale Oil Corporation, which was followed into this field in 1931 by the Home Oil Company, and in 1933 by the Independent Refining Company.

During the period of seven years which have since elapsed, small amounts of road oil and asphalt have been made in other Montana plants, some no longer operating, but the total is negligible and the facts and figures covering the operations of these three major independent plants give a practically complete picture of the development of this industry in Montana. Such references as may be made to other plants will be merely for the purpose of clarifying and reconciling the figures presented.

The Independent Oil Refining Industry of Montana Today

Manufacture of road oil and asphalt is, of course, only one branch of the independent oil refining industry in Montana, and before going into that angle of it in detail you might be interested in a composite picture of the industry as a whole, as represented by these three major establishments. I shall make it brief. The figures, let me add, are close approximations in round numbers.

The operations of these companies represent a combined investment of $3,000,000.00.

The combined capacity of their plants is 13,000 barrels of crude oil per day or 4,750,000 barrels per year.

The combined production capacity of their road oil and asphalt plants is 9,000 barrels per day or 3,285,000 barrels per year or in gallons, approximately 375,000 per day or 135,000,000 per year.

Their consumption of crude oil for 1935 (figures for remainder of year being estimated, as in the case likewise of other totals for the current year) will aggregate 2,175,000 barrels or slightly less than 46% of capacity.

Their gross sales of all products for 1935 will aggregate 87,000,000 gallons.

These products include gasoline—you are all familiar with their brands—the Litening and Wildfire of the Yale Corporation; the Major and Silver of the Home, and the Laureleaf Gasoline and Autofuel of the Independent, also tractor fuel, kerosene, Diesel fuel, furnace and locomotive fuel, road oil and asphalts of all types, lubricating oils and greases and various other by-products.

These three refineries employ—in plant, office and sales force—an average of 315 men, the great majority of whom are heads of families, with a total annual payroll of approximately $450,000.

In addition, they give employment in the trucking of both crude oil and refined products to an average of 235 men, (including both wage workers and trucking contractors) involving an annual expenditure of approximately $275,000.

In other words, they give regular employment to some 550 men with an annual payroll of $725,000.

Their combined outlay for crude oil at the well in 1935,

all suitable Montana crude, by the way, being purchased by these plants, will total $1,400.000.

Transportation charges paid or borne—pipe lines, railroads and truck lines—including the payroll just mentioned, will total for the year approximately $3,000,000.

Their total purchases of supplies, exclusive of crude oil, and mostly in Montana, will amount to $600,000 for the year.

Their total tax payments—gasoline tax, federal and miscellaneous taxes for the year will aggregate $1,190,000.

In addition, it is estimated that the gasoline taxes paid by trucks engaged in hauling the crude oil and refined products will total $115,000 making total tax payments of over $1,300,000.

Of course, the gasoline tax is passed on to the ultimate consumer, as intended when established, but it is none the less a tax properly to be credited to the oil refining industry when the sources of the state's revenues are being considered.

Add to this the taxes paid by oil producers and carriers and we have quite a contrast to the $400 which comprised the state's total revenue from the oil industry only eighteen years ago.

These figures give an idea of the important part which the independent refining industry of Montana plays in the industrial life of the Treasure State and of the contribution it is making toward economic recovery.

Technical Development of Asphalt Refining in Montana

During the period covered by these figures, technical development of asphalt refining at these plants has kept pace with the increase in volume and markets, and likewise with new requirements.

A brief resume' of these developments will no doubt be of interest. For this we are indebted to Mr. T. R. Corbett, plant engineer for the Yale Oil Corporation. I shall quote Mr. Corbett verbatim:

"The years 1929 to 1935 have witnessed a steady advancement and development in the road oil specifications used by the State of Montana. Accompanying these advances in specifications there has been a steady improvement by the Montana refiners in manufacturing technique and equipment.

"At the outset the state set up specifications for four grades of oil which correspond roughly to four of the slow curing grades now in use. Looking over some of these early speci-

fication sheets, we notice first of all that the number of tests required for each grade was far less then than it is at present, and hidden away in the general description accompanying the exact test requirements we find the germ ideas for nearly all the later additions.

"These early road oils, being all of the slow curing type, required a specialized refining technique rathen than highly specialized refining equipment. At the same time, the Montana refiner was particularly fortunate in his raw material. He had available crude oils containing asphalt of a quality unsurpassed by any other crude oil known. His aim, both then and now, has been to so handle these crudes as to minimize the destruction of their inherent quality. Both to his raw material and to its careful treatment we can give the credit for the quality of these early oils.

"In 1935 the State of Montana first began the use of cutback road oils and at that time adopted the Asphalt Institute classifications, of slow curing, medium curing and rapid curing grades. This demand for the full variety of road oils and asphalts stimulated the refiners to further developments both in equipment and processing. Today, these Montana refineries can offer their trade steam distilled, vacuum refined, and air blown asphalts, both separately and blended together, pure and reduced with any type of cutting thinner. The variety of processing equipment coupled with the natural high quality of the crude oils they use place them in an enviable position from which they can be counted on to be able to supply asphalts and road oils meeting any specification in current use.

"In 1933 only one Montana refinery was equipped to make asphalts and cutback asphalts on a large scale. Since that time the other two major independent Montana refineries have equipped themselves with the latest type of vacuum distillation units so that all now have vacuum, air processing or steam distillation units that enable them to produce an infinite variety and a superior quality for which they are rapidly becoming famous in territory ever more distantly removed from their home state."

Development of Trucking Industry

While we are on the subject of methods, reference to the progress in transportation methods made by these Montana refineries is pertinent and brings out some interesting facts.

Delivery of road oil by truck originated in Montana in 1935 and at the present time these plants operate a total of between forty and fifty insulated trucks, of capacities ranging from 2,000 to 5,000 gallons each, in which road oil is delivered at application temperature up to a distance of 250 miles—a 10-hour haul, which is the limit of economical truck haulage. The heat loss in transit is approximately one degree per hour.

This method of transporting road oil reduces the cost of oiling, as it does away with rehandling and reheating, saves time and increases efficiency. During this year 7,000,000 gallons of road oil, or approximately 50% of the output of these plants, have been delivered by truck. In this respect Montana is far ahead of any other of the so-called oil states—is, in fact, the only state so far using truck haulage on a really extensive scale. Montana refineries also employ trucks to a large extent in the delivery of other refined products, as well as in the bringing in of crude.

Figures previously given bring out that the trucking of petroleum and petroleum products in Montana is an important branch of the refining industry, and if figures were compiled as to the investment it represents and its expenditures for fuel and other supplies, they would no doubt, prove a surprise to most people.

The Industry's Future

So much for the past history and the present status of the asphalt industry of Montana. Now briefly, what of the future?

That, of course, depends primarily upon markets. We may well believe that the success which has attended the comparatively recent innovation of making good roads out of bad ones by the application of oil products, assures the continuance indefinitely of this major outlet. In fact, we may logically anticipate that the practice will be extended until eventually every road used by motor vehicles will be oil surfaced.

Fortunately for the future of the industry, Montana and other adjoining states, with extensive highway improvement programs under way or in the offing, promise an ever larger outlet for Montana refineries in whose favor as regards the competition under way or in the offing, promise an ever larger outlet for Montana refineries in whose favor as regards the competition

of other states, are the important factors of superior products and cheaper and faster transportation.

But let this demand double and redouble, and these Montana plants are equipped right now to take care of it, as a comparison of capacity and output shows. The present refinery capacity of the road oil and asphalt plants of the Montana refineries is, in round figures, 135,000,000 gallons per year. Sales this year were 14,500,000 gallons. In other words, these plants can right now produce approximately **nine** times as much road oil and asphalt as they have a market for.

As a mater of precise fact, they are operating, however, not at 11% of yearly capacity, but at approximately 25%, as during the off season on highway construction, they convert their "bottoms" into fuel oil and coke, for which there is ready sale.

The Story in Summary

To sum up the whole story in a few words: The asphalt industry in Montana, starting from scratch less than a decade ago, has made phenomenal progress. It stands today on a sound and substantial footing with its continued expansion for an indefinite time to come seemingly assured.

What has been achieved would no doubt have been impossible had it not been for the fine spirit and cooperation which has prevailed between the State Highway Commission and these Montana refineries, and too much credit cannot be given the highway officials of the state for the support they have given to this home industry. At the same time, the refiners have always been ready and willing to employ their facilities and equipment in experimental work looking to the improvement and differentiation of grades, and to co-operate in other ways to mutual advantage, while it goes without saying that their introduction of the system of hot oil deliveries has been a distinct contribution to the efficiency and economy with which the highway improvement program of the state has been carried on.

And, of course, they stand ready to extend the same co-operation and service to all our neighbor states which find it necessary to go outside their own borders for these products.

MONTANA CONFERENCE ON MODERN BITUMINOUS PRACTICE

SECOND SESSION

NOVEMBER 13th, 1935

E. B. DONOHUE, ASS'T. STATE HIGHWAY ENGINEER
MONTANA, GENERAL CHAIRMAN

E. B. Donohue, General Chairman, called the meeting to order and presented Dr. Harry J. McGregor, Chairman Montana State Highway Commission.

ADDRESS BY

DR. HARRY J. McGREGOR, CHAIRMAN, MONTANA STATE HIGHWAY COMMISSION

To you highway engineers, and others interested in our highway problems, present at this meeting, I wish to make a personal plea. Although the constructing of good highways is the first essential of the successful engineer, he must now assume a new responsibility—the safeguarding of human life. Automobile deaths which totaled 36,000 in the United States last year are taking a larger toll of human lives than any disease on record, with the exception of influenza. Just as medical science through its research has succeeded in successfully combating every disease except the common cold, it is the task of the highway engineer to find a way to reduce the steadily mounting highway death rate.

I realize that there is another branch of your profession whose members are devoting their entire time to—the creation of automobiles. These engineers are creating machines which each year travel the highways more swiftly. Although your task is a difficult one, it is your responsibility to anticipate the demands of the modern automobile so that the highways will become increasingly safe and the death rate decrease.

In Montana we have just recently organized a State Highway Patrol which should go far toward curbing reckless driving, drunkeness on the highways and other hazards created

by drivers or automobiles. But although they may perform their duties efficiently, they cannot remove the highway hazards. This is the engineer's task.

Compare a State Highway Department with a medical clinic. Just as the clinic must have a business manager, a Highway Department must have a Commission. This Commission's duties should be that of keeping the public informed of highway developments and anticipating the desires of the public and of assisting the highway engineers in the carrying out of their projects.

It is my hope that in the next four years the Montana highway engineers will be placed on an efficiency basis similar to Civil Service. This system will insure their tenure in office regardless of any changes which may be made in the state government personnel.

One of the needs of highway work today is more intensive and intelligent research. This research work should not only facilitate the work of the highway engineers in building better roads, but would result in great economies for the public. I would like to see all states develop a system of research so that helpful information could be exchanged.

The Montana Highway Department will at all times give the fullest cooperation to the departments of other states in the exchanging of highway data, and in conclusion, I wish to welcome you all to Montana.

CONFERENCE BOARD

H. G. NEVITT, Chairman
Manager Road Oil & Asphalt Division,
Socony-Vacuum Oil Co., White Eagle Division

L. V. GARRITY, Laboratory Supervisor
Michigan Highway Department.

F. C. LANG, Professor of Highway Engineering
University of Minnesota & Engineer of Tests,
Inspections and Research, Minnesota Highway Commission.

P. G. POORE, Pre-Construction Engineer,
Montana Highway Commission.

N. F. McCOY, Highway Engineer,
Bureau of Public Roads, San Francisco, Calif.

C. F. RAMEY, Assistant Chief Chemist
Standard Oil Company of California

DISCUSSION

Benedict: (B. P. R.) Are calcium chloride treatments detrimental to subsequent bituminous surface treatments?

Lang: (Minnesota) Not in our experience. Our stabilization has all been done the years previous to surface treatments; possibly the calcium chloride concentration has greatly decreased in this period; possibly the amount should be decreased when an immediate surface treatment is to follow.

Garrity: (Michigan) Michigan experience indicates no trouble with bases stabilized a year or two previous to the bituminous treatment. Prime or tack coats before bituminous treatments are recommended.

Reagel: (Missouri) Calcium chloride is not used for stabilization prior to a Missouri bituminous treatment.

McCoy: (B. P. R.) California does not use calcium chloride for base stabilization. Some work has been done on stabilizing bases with asphaltic emulsions.

Roherty: N. Dakota — Stabilized gravel bases are necessary, but calcium chloride is not necessary and may be harmful.

Rader: Montana — I do not believe that the Mountain states have used calcium chloride successfully for stabilization of bases. Results are generally unsatisfactory for any high, dry altitude.

Perry: Iowa — Iowa has not used calcium chloride stabilization prior to bituminous treatment. The city of Ames has used a top course stabilization of 1″ for surfaces open to traffic for a considerable length of time.

McCoy: B. P. R. — How long does calcium chloride remain at the surface before leeching or dusting away?

Reagel: Missouri — Indications are that it is well gone in one year, however, no definite record is obtainable. Information may be secured from the Research Council.

Benedict: B. P. R. — What are the results of sodium chloride stabilization?

Garrity: Michigan — Some sodium chloride jobs laid on county roads seem to result in rugged but slightly more brittle mat than calcium chloride.

Nevitt: Socony-Vacuum — What is a general method of eliminating frost boils?

Lang: Minnesota — Where soil conditions or experience indicates frost boils, a gravel back-fill drained by the use of tiles (so as to eliminate reservoirs) with additional gravel for the road base seems most satisfactory. The base should not be made with the idea that it will take any treatment, but should be designed to suit conditions, materials and the type of surfacing.

Reagel: Missouri — Bases of 15″ or 18″ mentioned in the discussion of adobe soils would be impracticable for us. Bases around 3″ to 8″ are more customary in our state, even on clay soils.

Johnson: (Montana) What is adobe?

McCoy: (B. P. R.) Adobe is a very stiff, heavy clay, which has an unusual affinity for water and a very high shrinkage. Because of this it is necessary to have heavy bases; the base is strictly a question of cost per mile, type of gravel, base requirements and type of surfacing.

Nevitt: (Socony-Vacuum) It is necessary to have a flexible mat so that if breaks occur it will heal.

McCoy: (B. P. R.) It is advisable to limit the amount of flexing.

Nevitt: (Socony-Vacuum) Flexibility is a relative term to distinguish this type from completely rigid surfaces.

Nevitt: (Socony-Vacuum) What are Michigan's experiences in connection with this question of foundations above the subgrade?

Garrity: (Michigan) Everything done has been experimental. Our experience is limited to the slow-curing type of oils.

McCoy: (B. P. R.) New Mexico adobe experiences of road mix over adobe subgrade in 1927 and 1928 have been varied. Any failures seem to be due to the quality of the fines and the tolerance of the 10-mesh material. It seems advisable to eliminate all below 10-mesh and have a clean, open-graded gravel.

Nevitt: (Socony-Vacuum) Is dust harmful?

Donohue: (Montana) Using RC-3, we have done considerable experimenting with various kinds of fine material and had good results with it. Fifteen to twenty-five per cent seemed advisable, but good results were obtained with lower percentages. The New Mexico material may be very porous and thus may require a higher percentage of asphaltic binder.

Poore: (Montana) Does a wide range of temperature cause asphalt road failure, and does it influence the choice of materials?

Rader:
Montana

Some failure due to extreme temperature changes may be noticed in the heaving of the surface.

Nevitt:
Socony-Vacuum

Inability to withstand impacts is where the failure occurs. Higher bitumen content improves the impact resistance. It is necessary to have the proper asphalt and asphalt content to give the necessary strength and consistency. The latter is necessary to permit plastic yielding.

McCoy:
B. P. R.

In this respect California has deformation and stability aggregate tests. Results indicate that cutbacks with cracked residue bases are unsatisfactory.

Garrity:
Michigan

Michigan has a hardening requirement in their specifications, eliminating cracked materials on the basis of the action of the material in the mat immediately after laying.

Muir:
Utah

We have an experience record and have used cracked materials which have proven very successful with the proper control.

Lang:
Minnesota

Does one use a high percentage of binder when using cracked asphaltic materials?

Ramey:
Stand. Oil Calif.

Yes, by weight, due to higher specific gravity.

McCoy:
B. P. R.

In your experience, have you had any failures that you have traced definitely to the asphalt itself, that you know are not due to subgrade, etc.?

Reagel:
Missouri

Yes, I have in mind a single project where an SC oil was used in an oil mat. The road stood up very well for one winter and then excessive failure occurred due to the checking of the surface. The oil was found to be excessively cracked.

Shanley:
Universal Oil-Illinois

Might this happen to any unsatisfactory construction, and not be due to cracking?

Nevitt: Socony-Vacuum — It might, but there are cases where it can definitely be proved that the material was responsible.

Mason: Montana — Excessive cracking can be controlled to some extent by a high $CC1^4$ solubility.

Reagel: Missouri — We have this included in our specifications.

Nevitt: Socony-Vacuum — New Mexico, a number of years ago, had definite proof of failure involving a cracked oil. Tests showed the same as California oil on an identical adjacent stretch, but failure occurred in the overheated oil in a few months.

Roherty: N. Dakota — Another indication of a quality product in spite of numerous objections is a low temperature ductility requirement.

Garrity: Michigan — Of interest here might be an experience Michigan had with two cracked materials, laid down on two portions of the same job. One began to powder and blow away shortly after application; the other was satisfactory. The asphalt that failed showed a drop in penetration from 55 to 18 upon extraction. The satisfactory asphalt dropped to 15.

Nevitt: Socony-Vacuum — We lack a direct tie between the laboratory tests and the results of the materials in use. What can be done?

Corbett: Yale Oil Co. Montana — We should work out the situation on cracked products from tests on materials showing such results in use. Polymerization may be the cause of failure.

Nevitt: Socony-Vacuum — It will be necessary to bring in both oxidation and polymerization, but this has not been done as yet.

Nevitt: Socony-Vacuum — Practice in Washington and Oregon has not been discussed. What is the situation there?

Newland:
Washington

A heavy base followed by a light surface seems satisfactory for our conditions. The road mixes have been practically abandoned, nor do we believe in light aggregates. What our state needs is a stabilized road followed by a penetration job. We do not take much stock in surface moisture difficulties.

Nevitt:
Socony-Vacuum

The aggregate in these states is much different than elsewhere. The majority must be produced from talus slopes, etc., by crushing, making heavy coarse aggregate bases with thin surface treatments economical. It is necessary to take into consideration the location, the available aggregate, and the conditions.

Reagel:
Missouri

The fact that extremely heavy bases seem to be regarded necessary by the Western States is not borne out by the experience of Missouri. Such bases would be out of the question on a cost basis. Satisfactory roads that give excellent and economical service are made by using light bases and road mix or plant mix mats.

Conference on:

PRACTICAL APPLICATION OF ASPHALTIC MATERIALS WITH PREPARED AGGREGATES.

CONFERENCE BOARD

TOM PERRY, Chairman,
Bituminous Engineer,
Iowa State Highway Commission.

A. H. BENEDICT, Materials Engineer,
Bureau of Public Roads, Portland, Ore.

J. R. PHILLIPS, District Engineer,
Wyoming State Highway Department

LEVI MUIR, Materials Engineer,
Utah State Road Commission.

J. N. ROHERTY, Research Engineer,
North Dakota State Highway Commission.

E. A. STODDARD, Ass't. Materials Engineer,
Iowa State Highway Commission.

DISCUSSION

Hart:
Montana

I would like information as to the effectiveness of non-skid (bitumen with cover aggregate) treatments with SC bitumen.

Muir:
Utah

In 1931 Utah had sealed 750 miles of surface which was not considered a satisfactory non-skid treatment, due to the fact that the size of aggregate used was too small. A later treatment of 500 miles with ¼ gallon of bitumen with ⅜″ to ⅛″ aggregate, gave satisfactory results.

Newland:
Washington

A 95 penetration asphalt was used in Washington for summer treatments and in 1935 two applications were used of 1/10 to 12/100 gallon each application, which gave satisfactory results.

Stoddard:
Iowa

I understand the Research Council is undertaking a study of specifications for bituminous materials, which will aid in making a better selection of materials for various uses.

Hart:
Montana

I would like information regarding construction methods used applying seal coats.

Muir:
Utah

The practice in Utah is to broom the surface 2′ wider than the section on which the bitumen was spread and the surplus aggregate swept from the surface discourages traffic from using the treated portion. For application of 1/10 gallon no cover was used and for applications of ¼ gallon stone chips were distributed from spreader boxes.

Following the application of stone chips, the surface is smoothed with a broom drag 18′ long with four cross members of rubber belting. After smoothing, the surface is rolled with an 8 or 10-ton roller. After rolling, the surface is again covered with the drag and motor patrols. Considerable material is pushed to the outer edges from brooming and blading operations and this condition automatically discourages traffic from using the shoulders.

Nevitt:
Socony-Vacuum

I would advocate sealing a porous surface with a bitumen which will fill the voids and still preserve the hard, non-skid surface.

Perry:
Iowa

The practice of sealing will, over a period of years, reduce the non-skid surface.

Nevitt:
Socony-Vacuum

Wyoming seals the surface every year, and in my opinion the surfaces are consequently oversealed so far as securing satisfactory non-skid surfaces is concerned.

Kay:
Wyoming

Each year there is some wear on the surface and consequently an additional treatment is justified. In Wyoming the practice is to apply ¼ gallon RC-2 bitumen to half the roadway and leave uncovered approximately two hours before

applying aggregate with a rotary spreader. This permits the volatile portion to evaporate and the aggregate is held in place when spread. The surface is not dragged after spreading the aggregate because such operations turn the aggregate exposing the treated surface, which consequently reduces the non-skid qualities of the finished surface and lessens the visibility. Traffic is not permitted on the treated portion of the roadway until twenty-four hours after treatment. If detours are not available, traffic is handled by flagmen.

Lang:
Minnesota

Have you any information as to new methods which may have been developed for improving the visibility for night travel on bituminous surfaces?

Kay:
Wyoming

The use of light colored aggregate for cover material will give good results in two ways; the surface retains a lighter color, and material displaced to the edges of the roadway leaves a light colored edge which is readily visible to the driver.

Hart:
Montana

What is the usual cost of non-skid treatments?

Perry:
Iowa

Approximate costs for treatments without cover are from $150 to $200 per mile and for treatments with cover aggregate the cost is from $650 to $700 per mile.

Nevitt:
Socony-Vacuum

I believe those figures are a fair average.

Perry:
Iowa

I think it remarkable that of 200 miles constructed in Utah in 1935, no "spotting" was required to secure the desired bitumen content.

Muir:
Utah

The windrow of aggregate to be treated was made uniform before applying bitumen by measuring the windrows every 25 feet and the material redistributed as necessary.

Nevitt:
Socony-Vacuum

Although tests of absorptive qualities of aggregate by the use of water was apparently satisfactory, yet it was desirable to make these tests with the bitumen to be used in the mix.

Muir:
Utah

The Utah method does check the absorption by the use of bitumen, although the initial test is made with water, and although final tests for absorption are run for thirty days, yet satisfactory results for field use can be secured after three or four days.

McDowell:
Montana

Regarding the use of a mechanical measuring device to secure a uniform windrow cross-section of dry aggregates, we found that the use of such a device, mounted on the frame of a 10-foot blade, on two miles of construction, had not proven satisfactory.

Roherty:
N. Dakota

North Dakota has secured satisfactory results by placing the aggregate on the road with a measuring box.

Kay:
Wyoming

We advocate laying heavy mats of 2½″ to 3″ compacted thickness in two layers, each of which should be compacted by proper rolling.

Lang:
Minnesota

We believe it very necessary to level the base course before placing the surface course; particularly is this true when retreating an existing surface.

Muir:
Utah

It is advisable to lay heavy mats of plant mix in two courses, the first course to be 1″ to 1½″ in thickness.

Roherty:
N. Dakota

I also believe better results will be secured if mats of 3″ compacted thickness are laid in two courses, and lighter mats in one course.

Gould:
Iowa

What is the prevailing practice as to compacting mats, are they laid in one course or more? Also what are the types and weights of rollers best suited to this work? Is the final compaction determined by a definite number of rollings or compacted to the satisfaction of the engineer?

Perry: (Iowa) I think we should discuss first the prevailing type of roller specified by the various states.

Donohue: (Montana) Tandem rollers of from six to eight tons, three-wheeled rollers, and pneumatic tired rollers have been used in Montana, and although not ready to make definite recommendations, I was not well impressed with results secured with the pneumatic type.

McCoy: (B. P. R.) I favor the use of tandem rollers of 10-ton weight because of super-elevated curves, but the use of this type is largely a matter of opinion.

Roherty: (N. Dakota) Pneumatic tired rollers are giving good results in North Dakota and give more uniform compaction. However, with this type of roller, some dragging or light blading is necessary.

Donohue: (Montana) In our experience, the pneumatic tired rollers would not give compaction comparable to the steel tired. The pneumatic tired rollers did not push material above ¼″ into the mat and did not satisfactorily compact the larger sizes.

Perry: (Iowa) We would now like information as to the number of rollings specified or when sufficient compaction is generally considered as having been secured.

Lang: (Minnesota) In Minnesota, rolling is continued until, in the opinion of the engineer, sufficient compaction has been secured.

Benedict: (B. P. R.) The amount of rolling required to give satisfactory compaction is dependent upon the temperature of the aggregate at the time of rolling and the type or kind of material being used.

Muir: (Utah) It is advisable to keep the larger sized particles in the mix and carry traffic over the road while compacting. The loose material is bladed back and forth across the road to improve the surface as compaction progresses.

Kay:
Wyoming

Too much rolling sometimes eliminates the non-skid qualities of the surface, which suggeses the desirability of restricting rolling in the specifications to cover this point.

Nevitt:
Socony-Vacuum

Too much rolling of cutback surfacing gives a wedging action which is detrimental to the stability of the mat.

Newland:
Washington

Common practice in Washington requires rolling until the surface is sealed and the marks of the roller do not show.

Stoddard:
Iowa

Have any of the states here represented had experience with the roll-a-plane roller?

Lang:
Minnesota

It has been used in Minnesota on small jobs and has proven satisfactory. In my opinion it gives a smoother riding surface than other types.

Muir:
Utah

When this roller was used in Utah, the center wheel tore the surface and we have not considered it as applicable for bituminous work.

Reagel:
Missouri

From experience in Missouri, I do not believe it was better than other types for mat compaction. I consider rolling desirable in order to spread traffic over the full road surface.

An unidentified gentleman from the floor stated that he was not ready to recommend a definite type of roller nor the amount of rolling which should be required for bituminous construction.

Gilmore:
Asphalt Institute Mo.

In my opinion, the pull-type roller is satisfactory and sometimes a wide roller is desirable. From experience to date, the roll-a-plane roller gave a favorable account of itself.

Benedict:
B. P. R.

In discussing types of bitumen for various uses, I believe that cutbacks have increased in popularity. The Bureau favors the use of MC bitumens in road mix, but does not like them in plant mix. The Bureau recommends a heavy basic material for this use.

Roherty:
N. Dakota

In North Dakota we consider cutbacks as a modern product.

Muir:
Utah

In tearing up a mat in which cutbacks have been used, the solvent evaporates and leaves a dry mix.

Benedict:
B. P. R.

Mr. Muir, could a satisfactory surface be secured without eliminating the solvent?

Lang:
Minnesota

The use of MC bitumen in plant mix had proven satisfactory in Minnesota.

Benedict:
B. P. R.

My experience has shown that the mat wrinkles if too much kerosene is left in the mat when laid.

Muir:
Utah

On construction across a mud flat in Utah we used a cutback bitumen with 30% solvent and laid the finished mix without aeration with satisfactory results. This was a trial stretch laid several years ago, and no distortion has occurred as yet.

Nevitt:
Socony-Vacuum

(Discussed generally the subject of aeration of mats containing cutback bitumen and recommended sufficient aeration to eliminate the major portion of the solvent.)

Conference on:

TREATMENT OF NATIVE SOILS IN PLACE AND SPECIAL METHODS REQUIRED.

CONFERENCE BOARD

F. V. REAGEL, Chairman,
Engineer of Materials,
Missouri State Highway Department

R. P. NEWLAND, Division Engineer,
Washington State Highway Department

L. D. CONKLING, Professor of Civil Engineering,
Montana State College.

SEWARD MASON, Testing Engineer,
Montana Highway Commission.

FRANK S. GILMORE, District Engineer,
The Asphalt Institute,
Kansas City, Missouri.

H. R. MacKENZIE, Chief Engineer,
Department of Highways,
Province of Saskatchewan.

DISCUSSION

MacKenzie: (Canada) Does not surface water injure an oiled earth surface?

Reagel: (Missouri) No, if proper drainage is provided. The crown should be ample.

Newland: (Washington) What is the procedure followed in the maintenance of oiled earth surface?
Patching is used for small surface breaks. The secret of patching is to pre-oil a supply of earth and allow to cure prior to use. Oil is dumped into an earth sump and allowed to penetrate then the oil-treated earth is excavated as needed for patching.

Newland: (Washington) What is the distance between teeth on the sub-oiling machine described?

Gilmore: Asphalt Institute Mo.

Teeth are set in V-shaped banks so that effective distance between them is approximately one foot.

The range of oil used on experimental suboiling projects varied from 3 to 7% by weight, based on the material passing 40-mesh sieve and on residue of oil of 100 penetration. Results indicate that 5 or 6% will be about the right per centage. Both SC and MC type oils seem to diffuse satisfactorily. Emulsification does not seem necessary.

MacKenzie: Canada

Is any difficulty experienced with clay pulverizing with ¼ gallon application?

Reagel: Missouri

The ¼ gallon application on oiled earth surfaces is for retreatment of the surface the second or third year. No difficulty is experienced because clay is already oil-treated even though treatment remaining may be lean.

MacKenzie: Canada

Can clays and gumboes be successfully treated?

Reagel: Missouri

We have satisfactory results with surface oiling of clays and gumboes. The cost per mile will approximate, including maintenance, $600 per mile the first year, $240 per mile the second year and $200 per mile the third year. These surfaces will carry an unlimited volume of rubber-tired traffic and can be kept mud and dust free for years by annual retreatment. They will, however, show distress under mutilative types of traffic.

Lang: Minnesota

Trouble has been experienced with flaking of oiled surfaces.

Nevitt: Socony-Vacuum

Cutback material might correct flaking.

Gilmore: Asphalt Institute Mo.

Bituminous treatment of fine sand in Nebraska are laid in two courses to permit curing of the first course prior to sealing. If not allowed to cure, the trapped solvent causes lack of stability.

The treatment is extended over the entire width of traveled surface. Carrying treatment over shoulders greatly reduced erosion.

Gilmore: Asphalt Institute Mo. — Does scoria resemble a gravel and is it used in the same manner?

Conkling: Montana — It is used as a substitute for gravel.

Nevitt: Socony-Vacuum — It is similar to mine dump shale but harder. Mine dump shale is not satisfactory, failing due to excessive wear.

Pictures—Scoria Surfaces

L. D. Conkling, Professor of Civil Engineering, Montana State College, presented two reels of pictures in connection with his paper on "Scoria Surfaces," which viewing was the subject of much interest and some discussion.

J. N. Roherty, North Dakota Highway Department Research Engineer, discussed generally the characteristics of scoria aggregate as found in his state and as compared to those samples of the Montana product, as exhibited by Professor Conkling in connection with his paper.

ENTERTAINMENT

MONTANA CONFERENCE ON

MODERN BITUMINOUS PRACTICE

November 12, 13, 1935.

The entertainment features were very unique and highly enjoyable. On the evening of November 12, a banquet was held at the Finlen Hotel followed by a floor show and dancing. Mr. R. H. Fletcher, Plans Engineer of the Montana Highway Commission, acted as master of ceremonies and presented a fine program of songs, dances, and humorous talks.

On November 13th, a stag party and floor show were held at the Golden Fan Nite Club in Meaderville with approximately 140 persons in attendance. Short talks and comments on the Conference were made by representatives of each state and Canadian province at the Conference, and all were very enthusiastic in praise of the manner in which all phases of the Conference, both business and social, had been conducted.

A very enjoyable dinner party was also given for the ladies at the Rocky Mountain Club on November 13th.

The entertainment was sponsored by the following Montana manufacturers of bituminous products:

The Yale Oil Corporation, Billings Montana;

Home Oil & Refining Company, Great Falls, Montana;

Independent Oil & Refining Co., Billings, Montana.

REPRESENTATIVE WESTERN HIGHWAY ENGINEERS PRESENT AT MONTANA CONFERENCE ON MODERN BITUMINOUS PRACTICE

Front Row, From Left to Right—A. H. Benedict, Materials Engineer, Bureau of Public Roads, Portland; H. R. MacKenzie, Chief Engineer, Department of Highways, Regina, Saskatchewan; F. W. Reagel, Engineer of Materials, Missouri Highway Department; F. C. Lang, Engineer of Tests, Minnesota State Highway Commission; Tom Perry, Bituminous Engineer, Iowa Highway Commission; R. P. Newland, Division Engineer, Washington State Highway Department, and Levi Muir, Materials Engineer, Utah State Road Commission.

Back Row—E. B. Donohue, Assistant State Highway Engineer, Montana Highway Commission; D. A. McKinnon, State Highway Engineer, Montana Highway Commission; L. V. Garrity, Laboratory Supervisor, Michigan Highway Department; J. F. Jacobs, District Engineer, South Dakota Highway Commission; N. F. McCoy, Highway Engineer, Bureau of Public Roads, Regional Office, San Francisco; J. N. Roherty, Research Engineer, North Dakota Highway Commission; J. R. Phillips, District Engineer, Wyoming Highway Commission, and C. M. Ehllen, Engineer, Idaho.

MONTANA CONFERENCE ON MODERN BITUMINOUS PRACTICE

November 14, 1935, 10:00 A. M.

CONCLUDING SESSION

A short morning session was held at which arrangements were made for the field inspection trips to start at 1:00 P. M.

After some discussion of plans for the holding of the Conference annually, and all those present enthusiastically expressing a desire that these plans be carried forward, the meeting was adjourned by General Chairman D. A. McKinnon, who announced that the results of the Conference had been very gratifying, showing that the highway engineers of the West and Mid-West realized the importance of this type of construction, and that the Montana Conference on Modern Bituminous Practice would be held annually hereafter.

GENERAL FIELD INSPECTIONS

Nov. 14, 1935, 1:00 P. M.

COMMITTEE IN CHARGE:

SCOTT P. HART.....Maintenance Engineer
N. W. HICKS.....Division Engineer
A. W. ENGEL.....Equipment Superintendent
D. L. CHENEY.....Ass't. Bituminous Engineer

Arrangements had been made for three inspection trips, a trip to Helena to view the earthquake damage and inspection of oiled roads enroute; a visit to the Anaconda Copper Company smelter at Anaconda and inspection of oiled roads enroute; and a trip through the Leonard mine, one of the largest copper mines in Butte; and an inspection trip over roads in the vicinity of Butte. The majority of those present, of course, selected the trip to Helena and the earthquake area, but all trips were well attended and were very interesting and enjoyable.